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Editor's Page

Addressing water scarcity

The threat of water scarcity may not be a top concern for those who have readily available freshwater to meet their daily needs. But for about two billion people who currently live in areas experiencing high water stress and the approximately four billion who suffer from water scarcity at least one month a year, it is a stark reality. These are the numbers approximated by UNESCO (United Nations Educational, Scientific and Cultural Organization; en.unesco.org) in its report, "The United Nations World Water Development Report 2019: Leaving No One Behind." While the Earth's surface is approximately 70% water, only about 2.5% of that is freshwater, and less than half of that is readily accessible freshwater. UNESCO says that global water use has been increasing by about 1% per year since the 1980s and is expected to increase at a similar rate until 2050. This means an increase of 20–30% more water being used compared to today. Industrial and domestic water use are the main drivers for the expected rise in demand. While agriculture draws the largest water demand at about 69% of worldwide annual water use, industrial use accounts for 19% and domestic use about 12%.

Industrial water

A recent report by *Raconteur* (www.raconteur.net) in association with the World Economic Forum and British Water, called "Future of Water," highlights water supply challenges. In the report, Alexander Lane, DuPont Water Solutions' commercial director said, "Eighty percent of the water that is produced is released back to the environment. That's already a source of reasonably well treated water that should be tapped, rather than just letting it go down the drain. We need to shift our thinking from linear to circular: reduce usage firstly, yes, but also then look at ways we can recycle and treat the water we have." Thinking in terms of a circular economy is indeed a growing focus of many companies in the chemical process industries (CPI), and water stewardship is an important part of this effort.

Much work is underway to improve technologies for more efficient water use, better water and wastewater treatment, and understanding and measuring the chemistry of water treatment. See, for example "A Solvent-Extraction Approach for Desalination of High-Salinity Brines" in last month's issue of *Chemical Engineering* (p. 6), "A New Membrane for Forward Osmosis" (*CE*, April 2019 p. 7), "Industrial-Grade Salt Recovery from Zero-Liquid Discharge Process" (*CE*, February 2019, p. 7), an article that addresses how breweries are looking at water management (*CE*, November 2018 pp. 14–17) and our current cover story on water chemistry (pp. 24–29).

And this month, an annual event that brings much needed focus to water-related technologies and issues is taking place in Chicago. Our preview of Weftec (www.weftec.org) on p. 27 gives more details. ■

Dorothy Lozowski, Editorial Director

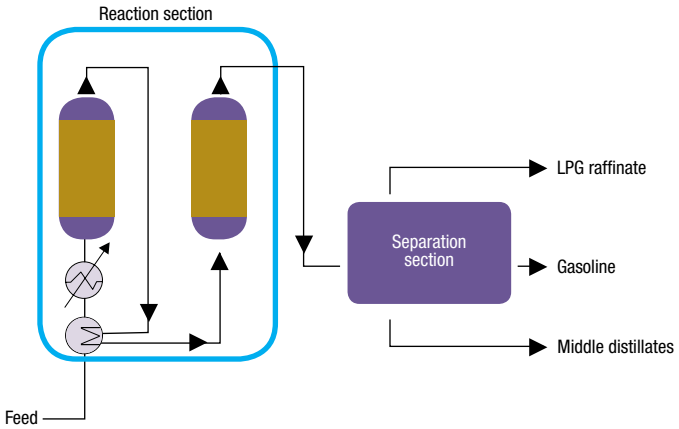
In Memoriam

Christopher Ross, VP of sales for Charles Ross & Son Company, passed away on July 31. Chris worked in his family business for almost 30 years and was a long-term reader and supporter of *Chemical Engineering*. One of his company's most recent contributions to the pages of *Chemical Engineering* was the article "Beyond Simple Mixing," which appeared in our August issue. We extend our sincere condolences to his family, friends and colleagues.

photo: Charles Ross & Son Co.

Commercial debut for an upgrading process

After four years of project development and execution, the new PolyFuel unit at Petrobrazi petroleum refinery in Romania has been started-up and is fully functional since April 2019. Based on the PolyFuel technology licensed by Axens (Rueil-Malmaison, France; www.axens.net), the OMV Petrom's project at the Petrobrazi refinery enables operators to increase the fluid catalytic cracking (FCC) products value by upgrading liquefied petroleum gas (LPG) and light cracked naphtha into high-quality fuels. "The PolyFuel unit of Petrobrazi refinery is the first of its kind valorizing C4 and C5/C6 fractions into high-quality gasoline and middle distillates [diesel or Jet A1, or both], increasing the overall production of these products," says Bruno Domergue, Axens Clean Fuels, Bio, Olefins and Gas business line director.



In the PolyFuel process (flowsheet), light olefins are oligomerized catalytically in fixed-bed reactors operating in series. Conversion and selectivity are controlled by reactor temperature adjustment, while the heat of reaction is simply removed by feed-effluent heat exchange. The reactor section effluent is fractionated to produce a gasoline fraction with low olefins content and a middle distillates fraction. A spare reactor is provided to ensure a continuous operation of the process, thus avoiding unwanted FCC shutdowns. The management of the reactors is optimized to maximize catalyst run-length.

The PolyFuel process uses the IP 811 catalyst that was first commercialized for Selectopol and Polynaphtha technologies. Thanks to its high activity and stability, IP 811 can be operated at high severity to maximize the middle distillates fraction without cracking. It is regenerable several times, allowing over 95% activity recovery, says Domergue.

Additionally, compared to alternative catalysts for this application, IP 811 has no pressure drop associated with it, and the cycle length is not limited by pressure-drop issues.

This multifunctional photocatalyst splits water with visible light

Oxysulfide semiconductors have narrow bandgaps — a property that makes them suitable for water splitting under irradiation with visible light (640 nm wavelength). That's because the electronegative sulfide ions negatively shift the valence band edges of the corresponding oxides. However, the instability of sulfide ions during the water oxidation is a critical obstacle to simultaneous evolution of hydrogen and oxygen.

Now, a Japanese collaboration of industry, academia and government has demonstrated the activation and stabilization of $Y_2Ti_2O_5S_2$ (1.9 eV bandgap), as a photocatalyst for overall water splitting. On loading of IrO_2 and Rh/Cr_2O_3 as O_2 and H_2 evolution co-catalysts, respectively, and fine-tuning of the reaction conditions, simultaneous production of stoichiometric amounts of H_2 and O_2 was achieved on $Y_2Ti_2O_5S_2$ during a 20-h reaction. The fine particles of the photocatalyst could be handled by a simple spray-coating procedure to produce a photocatalyst sheet with a large surface-area. The discovery of the overall water-splitting capabilities of $Y_2Ti_2O_5S_2$ is expected to be applied for the inexpensive production of H_2, while extending the range of promising materials for solar-H_2 production.

The consortium is made up of researchers from the New Energy and Industrial Technology Development Org. (NEDO, Kawasaki City, www.nedo.go.jp) and the Japan Technological Research Association of Artificial Photosynthetic Chemical Process (ARPChem), which six industrial companies have joined, in collaboration with the University of Tokyo, Shinshu University and more.

Edited by:
Gerald Ondrey

NANOFILTRATION

Toray Industries, Inc. (Tokyo, Japan; www.toray.com) has created what is claimed to be the world's highest-level nanofiltration membrane. The new membrane triples the permeation performance of conventional models while enhancing ion and organic-compound separation from aqueous solutions.

In developing new membranes, the challenge is to balance a tradeoff between selective separation and permeation. Toray therefore began exploring a membrane mechanism that would help improve permeation. This resulted in a porous and protuberant structure that expanded the surface area, delivering selective separation greatly exceeding that of regular setups to triple water permeability, says the company.

Nanofiltration is used for removing organic solvents and agrochemicals from groundwater and rivers. Nanofiltration membranes are also used in the food and biotechnology fields, notably to desalinate soy sauce and dairy products, and to purify amino acids and lactic acid.

The company will accelerate development of the new membrane, scaling it up with a view to commercialization within the next three years. Anticipated applications include water treatment, resource recovery and biorefineries.

METHANOL CATALYST

Scientists at ETH Zurich (Switzerland; www.eth.ch) and Total S.A. (Paris, France; www.total.com) have developed a new catalyst that converts CO_2 and H_2 directly into methanol. The new catalyst is based on indium oxide, which was developed by Javier Pérez-Ramírez, professor of Catalysis Engineering at ETH Zurich, and his team. A few

(Continues on p. 8)

years ago, the team successfully demonstrated that In_2O_3 was highly selective for producing methanol, with only water as a side product. Although the catalyst also proved to be highly stable, the activity was not sufficiently high for being a commercially viable option.

The team of scientists has now succeeded in boosting the activity of the catalyst significantly, without affecting its selectivity or stability. They achieved this by promotion with palladium. "We insert some single palladium atoms into the crystal lattice structure of the indium oxide, which anchor further palladium atoms to its surface, generating tiny clusters that are essential for the remarkable performance," explains Cecilia Mondelli, a lecturer in Pérez-Ramírez's group. Details are described in a recent issue of *Nature Communications.*

ETH Zurich and Total have jointly filed a patent for the technology. Total now plans to scale up the approach and potentially implement the technology in a demonstration unit over the next few years.

AMMONIA OXIDATION

Conversion of ammonia into dinitrogen has attracted broad scientific interest in relation to molecular models of the heterogeneous nitrogen-fixation process, environmental treatment for denitrification and utilization of NH_3 as an energy carrier. The research groups led by professor Yoshiaki Nishibayashi at the University of Tokyo (Japan; https://park.itc.u-tokyo.ac.jp/nishiba) and professor Ken Sakata at Toho University have shown that some ruthenium complexes bearing 2,2'-bipyridyl-6,6'-dicarboxylate ligands work as catalysts for the ammonia oxidation reaction. They also verified that the conversion works not only as an oxidative agent, but also under electrochemical conditions which means the new catalyst could be used as the anode for the electrochemical conversion of NH_3 into N_2. This later achievement has potential for NH_3-based fuel cells.

(Continues on p. 9)

New research solves debate over water-gas shift reaction mechanism

The water-gas shift reaction (WGS; in which water vapor is reacted with carbon monoxide over a copper-chromium-iron-oxide catalyst to yield hydrogen and CO_2) is of paramount importance to the chemical industry, as it is a primary route to producing H_2 for a host of industrial applications in petroleum refining, ammonia production, metal production, food production and others. Recently published research resolves uncertainty over the mechanism of the WGS reaction, and thereby aids efforts to design and synthesize improve catalysts for the reaction.

A team of scientists at Oak Ridge National Laboratory (ORNL; Oak Ridge, Tenn.; www.ornl.gov) used a host of in-situ characterization techniques, including neutron vibrational spectroscopy, infrared spectroscopy and near-ambient pressure X-ray photoelectron spectroscopy, as well as computational methods, to examine the surface of the CuCrFeOx catalyst under real-world WGS conditions and to identify the intermediate species for the reaction. In the past, two possible reaction mechanisms for the WGS have been debated — a "redox" mechanism involving the participation of atomic oxygen from the catalyst, and an "associative" mechanism, proceeding via a surface formate-like intermediate, the researchers explain. "The answer is important because it helps us identify the critical point in the reaction where hydrogen is generated," said ORNL researcher and lead author Felipe Polo-Garzon.

Because of changes in the catalyst that occur during the reaction, characterizing the material is difficult. Limitations in the measurement techniques left unanswered questions about how the surface chemistry changes during the reaction mechanism. The VISION beam line at the ORNL Spallation Neutron Source, a Dept. of Energy user facility, helped overcome the previous limitations and elucidate the actual WGS mechanism in conjunction with other techniques. The combined spectroscopic and kinetic evidence collected by the team shows that the reaction proceeds via the "redox" mechanism. According to the researchers' data, at high-temperature conditions, the catalyst loses oxygen atoms to make room for water molecules that dissociate and give off pure H_2.

The new mechanistic information opens pathways for the design and synthesis of new catalyst structures that could improve the cost and efficiency of large-scale H_2 production.

Integrated e-waste processing facility nears completion

Although it contains many valuable metals, electronic waste (e-waste) is an exceedingly difficult material stream to process, and the vast majority of e-waste is not recycled. EnviroLeach Technologies Inc. (Vancouver, B.C.; www.enviroleach.com) is currently preparing to start up a first-of-its-kind integrated processing facility in Vancouver that combines advanced separation technologies with proprietary chemistry to process up to 20 ton/d of e-waste. The process uses a novel equipment arrangement that includes a vacuum belt filter for solid-liquid separation, optical sorting and a leaching circuit to maximize recovery of several valuable product streams from e-waste. EnviroLeach's technology runs at ambient conditions and a neutral pH, with zero effluent water and no landfill waste, while exhibiting comparable recovery rates to traditional e-waste processing methods, says the company. Furthermore, e-waste dismantling is simplified, when compared to other processing methods, as the end-to-end process can handle any type of printed circuit board, as well as complete components, including modems and power supplies. "We can actually take a whole cable box and shred it, separating the steel first and removing the plastic casing. Then we will separate the aluminum and printed circuitboards, which are divided into the organic components and a metals concentrate that includes both precious and base metals," explains Todd Beavis, vice president, corporate development. Ultimately, the process results in at least five saleable product streams, including gold recovered through electrowinning.

Another unique facet of EnviroLeach's facility is a patented method to efficiently recover tin from circuitboard soldering. "Tin adds a lot of extra value that no one else is capturing. OEMs in particular are quite interested in tin," says Beavis. The tin-recovery step is currently running at laboratory scale, but the company foresees considerable scaleup in the next three to six months. The technology can also be used to recover other base metals, such as copper and lead.

Stabilized, purified silk protein serves as green chemistry platform

Scientists have long sought ways to take advantage of the high strength of natural silk protein in new materials, but its incorporation has been hindered by the inability to stabilize the protein in water. Now, a company known as Evolved By Nature (EBN; Boston, Mass.; www.evolvedbynature.com) has developed a process to purify and solubilize silk protein, allowing its use as a starting material for a host of different silk-based materials from the same chemistry platform.

EBN envisions the silk protein platform as a way to replace petroleum-based chemicals with environmentally friendly and better-performing materials. For example, EBN CEO Greg Altman says biodegradable silk can replace finishing compounds for textiles, replace synthetic emulsifiers and other additives in cosmetic products, and coat fabric in performance apparel.

The process to make what EBN calls Activated Silk begins with waste cocoons from silkworms in the natural silk fabric industry. The cocoons are subjected to an extraction process to separate two components of the silk — sericin and fibroin. The fibroin is dissolved in a specially developed salt solution that reversibly interrupts the hydrogen bonds that are present in the amino acid beta sheets (a common protein motif) of the silk protein. The solution then goes through a diafiltration process to remove the salt, leaving a silk protein dissolved in aqueous solution. The solubilized silk can then be used to bind with other molecules or polymers.

In bringing its Activated Silk to market, Evolved By Nature is pursuing two commercial markets initially: textile finishing and cosmetics. Altman plans for the company to expand into other areas in the near future. “There are over 75 unique molecular configurations for natural silk protein,” he says, “so we can manipulate the silk polymer to do a wide variety of things.”

MAKING CO FROM CO_2

A process that combines plasma and membrane technologies to split CO_2 into O_2 and CO is being developed by researchers at the Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB; Stuttgart, Germany; www.igb.fraunhofer.de) and the University of Stuttgart. The process — developed under the project “Plasma-Induced CO_2 Conversion for the Storage of Renewable Energies (PiCK),” which is funded by the German Federal Ministry of Education and Research as part of the Kopernikus projects for the Energy Transition — is made possible by the separation of oxygen using a new perovskite capillary membrane.

Scientists at the University of Stuttgart’s Institute of Interfacial Process Engineering and Plasma Technology (IGVP) have developed an electrode-

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less reactor to carry out the CO_2 splitting. Here, an atmospheric-pressure, microwave-induced plasma is generated by means of strong electric fields. "If electrons excited in this plasma collide with CO_2 molecules, this causes CO_2 to decompose into the desired products CO and O_2," explains IGVP scientist Andreas Schulz, who coordinates the project.

To prevent CO from reacting back with the oxygen produced in the plasma to form CO_2, O_2 must be constantly removed from the reaction equilibrium. For this purpose, IGB has developed a new ceramic membrane that can selectively separate O_2. "Since the membrane must be temperature- and CO_2-stable at the same time, we spin special ceramic materials, so-called perovskites, together with polymers into a thin-walled capillary," explains Thomas Schiestel, proj-

(Continues on p. 11)

New oxocatalyst demonstrated for vinyl chloride monomer production

Recently, Tosoh Corp. (Tokyo, Japan; www.tosoh.com) has applied a new, proprietary oxocatalyst in the oxychlorination process for making ethylene dichloride (EDC) from ethylene, HCl, and O_2 in its vinyl chloride monomer (VCM) manufacturing process. The performance boost anticipated from simulation studies of the new catalyst has been confirmed at some of the company's VCM plants, which have a production capacity of 500,000 metric tons per year (m.t./yr).

Tosoh first began operating a VCM plant in the 1960s using a proprietary oxychlorination process. Since then, the company has worked to improve the oxycatalysts. Ethylene oxychlorination over a $CuCl_2$-KCl/Al_2O_3 catalyst in a commercial scale plant was examined for two consecutive years, during which the performance of the catalyst gradually deteriorated. The spent catalyst exhibited signs of deterioration, such as an increase in the K-to-Cu ratio induced by CuCl sublimation. In order to clarify how such changes in the catalyst component affect deactivation, kinetic studies and XANES ((x-ray absorption near-edge structure) analysis were carried out, and showed that an increased oxidation number of Cu elevated the activation energy of the oxychlorination catalyst. This change in activation energy would be one of the factors in the deactivation of the $CuCl_2$-KCl/Al_2O_3 catalyst at the scale of a commercial plant. Such changes in the activation energy could help predict the catalyst life in the plant.

Tosoh's latest proprietary oxycatalyst is said to represent significant progress in performance. In spite of its simple copper-catalyst composition, it features a cylindrical shape and a unique pore structure in the support, enabling high-performance capabilities, such as high activity, selectivity for EDC and durability.

Tosoh is expecting to aggressively strengthen its competitiveness by converting to the new oxycatalyst at its other VCM manufacturing facilities over the next few years.

A less expensive way to make graphene

A team from RMIT University (Melbourne, Australia; www.rmit.edu.au) and the National Institute of Technology, Warangal (Warangal, India; www.nitw.ac.in) has developed a cost-effective and eco-friendly way of producing graphene using a eucalyptus polyphenol solution extracted from eucalyptus bark. RMIT's professor Suresh Bhargava says the team's method could reduce the cost of producing graphene from $100/g to $0.5/g.

The most common method for synthesizing graphene oxide is chemical reduction. This method, however, relies on reducing agents that are dangerous to people and the environment. The team's method produces graphene with a quality matching the traditionally produced graphene without the toxic reagents.

The reducing ability of polyphenol compounds present in the eucalyptus bark extract is responsible for the reduction of exfoliated graphene oxide to soluble graphene under reflux conditions in an aqueous medium. Transmission electron microscope (TEM) and atomic force microscope (AFM) images show straight corroboration for the development of 1–4 layers of graphene. The team says the stable and homogeneous dispersion of the eucalyptus graphene in various solvents confirms the powerful interactions between eucalyptus polyphenol compounds and graphene.

Various methods to evaluate the electrochemical performance of the eucalyptus graphene have shown that the eucalyptus graphene supercapacitor has a high specific capacitance of 239 F/g and a high energy density of 71 Wh/kg at a current density of 2 A/g. These characteristics demonstrate that the team's green approach has an excellent prospect, not only in the fabrication of high-performance supercapacitors, but also in the synthesis of graphene-based materials.

The outlook for hydrogen as an energy carrier

Many countries are now making rapid advances in hydrogen energy technologies and strategy, and the rest of the world has much to learn from their experience, according to a new report — Advancing Hydrogen — compiled by a team from the University of Adelaide (Adelaide, Australia; www.adelaide.edu.au) and released by the Future Fuels Cooperative Research Centre in Australia on July 31.

The report contains 19 summaries of strategies and roadmaps from around the world. It sheds light on how countries, regions and industries are thinking about the potential for H_2 and helps develop other H_2 roadmaps and strategies.

According to the report, the developments around the world suggest we could see large-scale and rapid deployment of H_2 technologies from about 2030. Until then, the focus will probably remain on testing and developing technologies.

The most attractive method for producing H_2 is through water electrolysis powered by renewable energy, because it provides a zero-carbon source of H_2. However, the costs of water electrolysis are still two to four times higher than steam methane reforming.

The report says the fluctuating cost of electricity and discrepancy in energy credits are the two main barriers to large-scale hydrogen production through electrolysis (For more on hydrogen, see pp. 18–21).

These magnetic 'nanosprings' decompose microplastics

Microplastics — a subgroup of plastics with an effective diameter less than 5 mm — are ubiquitous pollutants. They adsorb organic and metal pollutants that are ingested by aquatic organisms, and accumulated all the way up the food chain.

Using tiny coil-shaped carbon-based magnets, researchers from the University of Adelaide (Adelaide, Australia; www.adelaide.edu.au), Edith Cowan University, Curtin University (both Perth, Australia), and Guangdong University of Technology (Guangzhou, China) have developed a new way of purging water sources of such microplastics without harming nearby microorganisms. "Carbon nanosprings are strong and stable enough to break these microplastics down into compounds that do not pose such a threat to the marine ecosystem," says Shaobin Wang, a professor of chemical engineering at the University of Adelaide.

To decompose the microplastics, the researchers generated short-lived, reactive-oxygen species, which trigger chain reactions that chop the long microplastics molecules into tiny harmless segments that dissolve in water. However, reactive-oxygen species are often produced using heavy metals, such as iron and cobalt, which are pollutants in their own right. The researchers found a "greener" solution in the form of carbon nanotubes laced with nitrogen to boost the generation of reactive-oxygen species.

Shaped like springs, the carbon nanotubes remove a significant fraction of microplastics in just 8 h while remaining stable themselves. The coiled shape increases stability and maximizes reactive surface area. Moreover, the springs become magnetic by the inclusion of a small amount of manganese. This makes it easy to collect them from wastewater streams for repeated use. ■

ect manager at IGB. The resulting green fiber is sintered at high temperatures to form a dense ceramic-capillary membrane. "Our perovskite membrane is stable in a CO_2 atmosphere and permeable for oxygen at temperatures of 800 to 1,000°C, but not to CO and CO_2," says Schulz.

EV BATTERY RECYCLING

Circa Group (Melbourne, Australia; www.circagroup.com.au) is participating in a project aimed at developing the first U.K. industrial-scale capability to reclaim and reuse the most valuable components of end-of-life electrical vehicle (EV) batteries. The Reclamation, Remanufacture of Lithium Ion Batteries (R2LIB) project is funded by U.K. Research and Innovation through the Faraday Battery Challenge.

Circa's bio-based solvent Cyrene is being used to recover polyvinylidene fluoride (PVDF) — a high-performance polymer widely used as a binder in Li-ion battery cathodes. PVDF processing currently relies on the use of N-methyl-2-pyrrolidone, which is a reprotoxic solvent that is under intense regulatory pressure.

Other partners in R2LIB include the University of York (which helped develop Cyrene), M-Solv (laser and robot modules for automatic handling and dismantling of batteries), ICoNiChem (recovery of Co, Ni and Mn), PV3 Technologies (recycled cathode production) and WMG (national facility for battery R&D). ❑

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Plant Watch

Ineos breaks ground for Bayport ASA plant

August 12, 2019 — Ineos Styrolution GmbH (Frankfurt, Germany; www.ineos-styrolution.com) hosted a groundbreaking ceremony for its new acrylonitrile styrene acrylate (ASA) plant in Bayport, Tex. The new site, which is designed for a production capacity of 100,000 metric tons per year (m.t./yr), is expected to be operational by 2021.

McDermott awarded FEED contract for PetroLogistics' new PDH plant

August 12, 2019 — McDermott International, Inc. (Houston; www.mcdermott.com) was awarded a contract by PetroLogistics II, LLC (Houston; www.petrologistics.com) to perform the front-end engineering design (FEED) services for a propane dehydrogenation (PDH) facility planned for the U.S. Gulf Coast. The plant has a design basis of 500,000 m.t./yr.

Tosoh to raise production capacity for chloroprene rubber

August 5, 2019 — Tosoh Corp. (Tokyo, Japan; www.tosoh.com) announced plans to increase production capacity for chloroprene rubber (CR) at the Nanyo Complex in Shunan City, Yamaguchi Prefecture, Japan. The investment in this expansion project is approximately ¥5 billion ($47 million). Once debottlenecking and expansion are complete in October 2021, the site's CR capacity will be 37,000 m.t./yr.

Linde starts up gas plant at Evonik's methionine complex in Singapore

August 2, 2019 — Linde (Munich, Germany; www.linde.com) started up a new gas-production facility supplying methane, hydrogen and carbon dioxide to Evonik Industries AG's (Essen, Germany; www.evonik.com) second world-scale methionine complex on Jurong Island in Singapore.

BASF to build tBA production plant in Nanjing

July 29, 2019 — BASF SE (Ludwigshafen, Germany; www.basf.com) plans to invest in a second production plant for *tert*-butylamine (tBA) at BASF Specialty Chemicals Co. in Nanjing, China. With this expansion, BASF's global annual production capacity of tBA will increase by more than 30%. The plant is planned to start up in 2022.

ExxonMobil starts up new polyethylene line in Beaumont

July 24, 2019 — ExxonMobil Corp. (Irving, Tex.; www.exxonmobil.com) started production on a new high-performance polyethylene line at its Beaumont, Texas polyethylene plant. The expansion increases plant production capacity by 65%, bringing site capacity to nearly 1.7 million m.t./yr.

Mergers & Acquisitions

Saudi Aramco intends to acquire stake in Reliance Oil-to-Chemicals division

August 13, 2019 — Saudi Aramco (Dhahran; www.saudiaramco.com) and Reliance Industries Ltd. (RIL; Mumbai; www.ril.com) have agreed to a non-binding letter of intent regarding Saudi Aramco's proposed investment in RIL's Oil-to-Chemicals (O2C) division, comprising the petroleum refining, petrochemicals and fuels marketing businesses of RIL. Saudi Aramco's potential 20% stake is based upon an enterprise value of $75 billion for the O2C division. This would be one of the largest foreign investments ever made in India.

Lanxess to divest its chrome chemicals business

August 12, 2019 — Lanxess AG (Cologne, Germany; www.lanxess.com) is selling its Chrome Chemicals business to Brother Enterprises, a Chinese leather-chemicals producer. The transaction is still subject to approval by the relevant antitrust authorities. Lanxess expects to complete the planned transaction by the end of 2019. The Chrome Chemicals business belongs to the Lanxess Leather business unit and generates annual sales of around €100 million.

Indorama to acquire Huntsman's integrated oxides and derivatives units

August 8, 2019 — Indorama Ventures Ltd. (IVL; Bangkok, Thailand; www.indoramaventures.com) has acquired the integrated oxides and derivatives businesses of Huntsman Corp. (The Woodlands, Tex.; www.huntsman.com). The purchase price is based on an enterprise value of around $2.1 billion. Under the terms of the agreement, Indorama Ventures would acquire Huntsman's manufacturing facilities located in Port Neches, Dayton and Chocolate Bayou, Tex.; Ankleshwar, India; and Botany, Australia.

KBR acquires isomerization technologies from RRT Global

August 8, 2019 — KBR, Inc. (Houston; www.kbr.com) has acquired isomerization technologies from RRT Global that will enable KBR to offer expanded octane and clean-fuel technology solutions. Since 2015, KBR, in alliance with RRT Global, has offered catalytic distillation technology for the isomerization of C5 and C6 *n*-paraffins to boost gasoline pool octane. Now, KBR has acquired the patented technology with intellectual property rights to offer isomerization technologies for C4 and C7 streams.

Air Products completes acquisition of GE gasification assets

August 6, 2019 — Air Products (Lehigh Valley, Pa.; www.airproducts.com) completed the acquisition of GE Power's gasification business. Financial terms of the transaction are not being disclosed. The gasification business acquired by Air Products includes GE's share of its 50-50 joint venture (JV) with China Shenhua Coal to Liquid and Chemical Co., a subsidiary of China Energy Group.

Chemours acquires Southern Ionics Minerals

August 5, 2019 — The Chemours Co. (Wilmington, Del.; www.chemours.com) acquired Southern Ionics Minerals, LLC (SIM; Jacksonville, Fla.), a minerals exploration, mining and manufacturing company handling titanium and zirconium mineral sands. This acquisition nearly doubles Chemours' internal ore-sourcing capacity. The acquisition includes a mineral-sands processing plant in Offerman, Ga. and an existing mine site in Charlton County, Ga..

Arkema to acquire photoinitiator specialist Lambson

July 30, 2019 — Arkema S.A. (Colombes, France; www.arkema.com) plans to acquire Lambson, a company specializing in photoinitiators for curing. U.K.-based Lambson reports sales of around €45 million.

Huntsman to acquire Sasol's stake in maleic anhydride joint venture

July 29, 2019 — Huntsman signed a definitive agreement with Sasol Ltd. (Johannesburg, South Africa; www.sasol.co.za) to acquire Sasol's 50% interest in the Sasol-Huntsman maleic anhydride JV. The JV owns a plant in Moers, Germany that has capacity to produce 230 million lb/yr of maleic anhydride. Huntsman will pay Sasol $92.5 million for the acquired stake.

Nouryon acquires China's largest triethyl aluminum manufacturer

July 25, 2019 — Nouryon (Amsterdam, the Netherlands; www.nouryon.com) has acquired Zhejiang Friend Chemical Co. (Friend), the largest Chinese producer of triethyl aluminum (TEAL) — a metal alkyl used in the production of high-volume polymers, such as polypropylene and polyethylene.

Clariant to divest Masterbatches business

July 25, 2019 — Clariant AG (Muttenz, Switzerland; www.clariant.com) has decided to divest its entire Masterbatches business, including both standard and high-value Masterbatches. These divestments will be concluded by the end of 2020. Clariant also plans to divest its Pigments business, as well as its Healthcare Packaging segment.

BP and Bunge create bioethanol JV in Brazil

July 22, 2019 — Bunge Ltd. (White Plains, N.Y.; www.bunge.com) and BP plc (London; www.bp.com) will form a Brazil-based JV, called BP Bunge Bioenergia. The 50-50 JV will produce a mix of bio-based ethanol and sugar at 11 mills in Brazil with a combined processing capacity of 32 million m.t/yr, while also generating renewable electricity. ■

Mary Page Bailey

3D Printing: Foundations for Mainstream Adoption

The seemingly boundless versatility of additive manufacturing makes it an area ripe for fast evolution, but critical industrial applications also demand verification and reliability

IN BRIEF

There is no doubt that 3D printing (also known industrially as additive manufacturing; AM) has set off a true manufacturing transformation, and the chemical process industries (CPI) are among numerous industrial sectors that are benefitting from its use. From rapid delivery of spare or replacement parts to design customization, the myriad AM technologies can help streamline maintenance activities, process improvements and research. Concurrently, materials engineers are actively expanding the boundaries of printable materials to include not only plastics and metals, but also nanomaterials, bio-based substances and more. However, as 3D-printed parts make their way into more end-use applications, and more companies begin operating their own in-house 3D-printing operations, it becomes clear that standardization and inspection are crucial for ensuring safety and reliability.

Penn State University

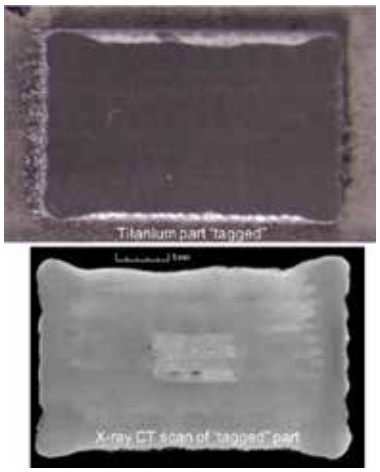


FIGURE 1. Chemical tags are a way to authenticate parts and protect proprietary designs

Building the baseline

The unprecedented flexibility available to manufacturers with modern 3D-printing/AM technologies also introduces some sensitive issues that the industry is just beginning to understand, in terms of safety, regulatory and intellectual property (IP) ownership. To address these concerns, Penn State University (University Park, Pa.; www.psu.edu) is offering a first-of-its-kind graduate course on legal issues in additive manufacturing. "With AM, a lot of companies are trying to do spares and repairs, but one of the challenges is that these companies don't necessarily own the part or design they are trying to replicate, and they may not realize they could be in violation of someone else's IP," says Tim Simpson, director of Penn State's Additive Manufacturing & Design graduate program. In some cases, says Simpson, replicating a part can be as simple as scanning the component and generating a 3D solid model from which the part can be printed. "People aren't used to thinking about ways to protect digital copies of their part," says Simpson. He is currently part of a team of researchers developing methods to authenticate 3D-printed parts, including embedded chemical tags — essentially a "fingerprint" that can be detected with spectroscopy to provide verification of a part's provenance (Figure 1). "If you're printing a titanium part, for instance, you can print a secondary material into the part that doesn't affect properties, but can be used to verify that parts are authentic," explains Simpson.

Verification and standardization are also essential when considering the safety aspects of employing 3D-printed parts in critical industrial applications, but the related standards for regulated industries are not fully realized as yet, even as AM's adoption flourishes in these sectors. For example, there are currently no ASME Boiler & Pressure Vessel Codes for AM components, but work is being done to develop new rules and code cases for 3D-printed structures. However, the fast proliferation of AM technologies demands that new standards be developed and updated very quickly. "From a spares and repairs standpoint, the pressure continues to mount. People want to do this quicker than the standards bodies are ready for," emphasizes Simpson. Key to these activities is cross-industry collaboration and sharing of data, especially in

demanding applications where there is cycling, fatigue or particularly high temperatures or pressures. The American National Standards Institute (ANSI; New York, N.Y.; www.ansi.org) and America Makes (Youngstown, Ohio; www.americamakes.us) have launched a standards-coordination effort to bring together relevant data for standardization of AM technologies and parts. "Rather than everyone developing standards independently that might overlap or conflict, there's some level of coordination, which hasn't really happened in the past," adds Simpson. Still, he adds, there is much work to be done, as many companies are reticent to share proprietary research or operating data, especially after spending millions of dollars to generate it.

Printed pressure vessels remain a particular area of interest, as are heat exchangers and heat sinks, but to move beyond the "spares and repairs" mindset and take full advantage of AM's capabilities, Simpson suggests that chemical processing companies should look to the new design freedoms enabled by AM. "The freedom to adapt and optimize materials — for instance, lightweighting a component with lattices — uses less material and enables viable business cases for using more expensive, longer-lasting materials. It can completely change the economics around the use case for a component."

Even with such potential for customization and process optimization, companies must continue to ensure that all parts of their facilities meet inspection requirements. "Independent verification and qualification are a way of mitigating risks and unknowns," says David Hardacre, lead specialist, Inspection Services at Lloyd's Register (LR; London, U.K.; www.lr.org). LR, in collaboration with TWI Ltd. (Cambridge, U.K.; www.twi-global.com), has developed a specific set of guidelines aimed at certifying metallic parts produced via AM, and has been certifying printing facilities since 2016. These guidelines examine many factors, including the following: feedstock receipt, storage and handling; equipment qualification; process control; personnel training; health, safety and environmental considerations; acceptance of deviations; and more. Recently, LR applied its guidelines to inspect and qualify a powder-bed fusion AM facility operated at Shell's Technology Center Amsterdam (STCA; www.shell.nl). "In 3D printing, many variables can influence the visual, chemical and mechanical properties of the printed part. This potentially introduces various risks to people, assets and the consistency of the parts produced. LR's qualification provides proof of competence in our AM processes and quality controls, thereby reducing operational risk," explains Ron van Wolferen, Emerging Technologies project manager and 3D Printing Theme Lead at Shell. Shell is developing AM projects to support assets across its entire enterprise, including seabed scans, newly shaped parts used for debottlenecking projects in hydrocarbon processing and replacements for obsolete parts (Figure 2) and research equipment, says Van Wolferen. Currently, the company is developing what is said to be the world's first 3D-printed pressure vessel. In such pioneering endeavors, says LR's Hardacre, it is important that companies strive for qualification, not only to satisfy legal and safety requirements, but also to contribute to the collaborative learning within the supply chain, which will benefit the entire industry. "As new technologies develop, standards and regulations also require development to incorporate these new ways of working to ensure that they are safe, that legal requirements are met and to provide assurance of quality and capability to end users," he continues.

As more groups begin to develop their own in-house printing operations, AM standards will certainly continue to evolve as the application areas expand. Currently, there is a single level of AM facility qualification, but it can be tailored to the specific AM process and materials being used within the facility, explains Hardacre. The certification requirements for printed parts may differ, depending on the risks and demands of the end-use application. "Different AM processes, different feedstocks and even different material groups impact the required testing and inspection to provide the level of confidence that the materials are fit for purpose," he adds. Moving forward, LR is contributing to several committees to further develop standards so that AM can be used safely and reliably across many industrial sectors.

Shell

FIGURE 2. Shell operates a powder-bed fusion AM facility at its Technology Center Amsterdam

Mastering new materials

One of the most exciting areas of activity is the evolution of new materials to expand the end-use applications for 3D-printed parts.

Modified steel. A research project at the Graz University of Technology (Graz, Austria; www.tugraz.at) seeks to expand the applicability of stainless-steel powders in selective laser melting (SLM) AM. In SLM, components are modeled as computer-aided design (CAD) files and then sliced into thousands of very thin cross-sectional slices, which are translated into vectors that provide a path for a laser beam to selectively melt thin layers of a metallic powder. While SLM can successfully produce complex parts, it is limited by the angle that a printed surface can be leaned. At some leaning angles (usually below 30–35 deg), SLM requires support structures, which introduce cost and complexity into the process and lengthen printing and post-processing times. These support structures must be removed — often manually — and in some specific cases, cannot be removed at all, making the part unusable, explains researcher Mateusz Skalon. Skalon has developed a method for modifying the surface of stainless-steel particles so that a component's leaned surface does not deteriorate during printing, thereby reducing the costs associated with support

Mateusz Skalon

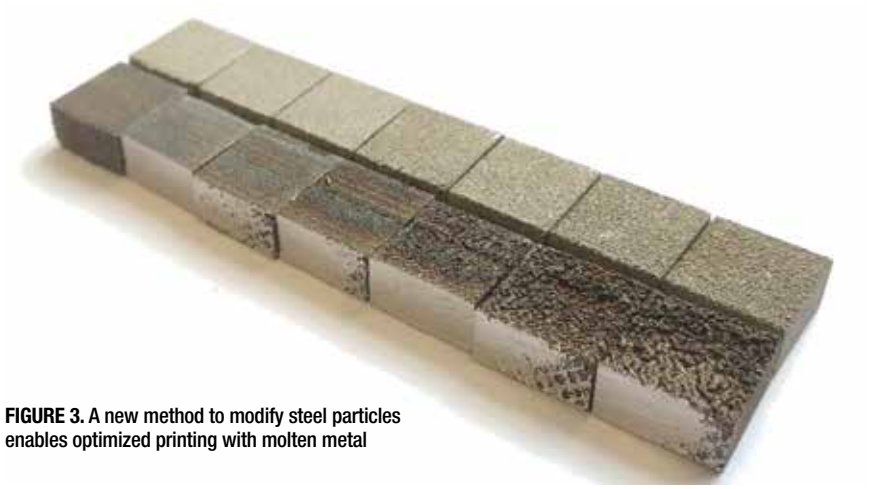


FIGURE 3. A new method to modify steel particles enables optimized printing with molten metal

structures. In SLM, a rapidly moving laser melts metal particles, creating a "track" of molten metal. This melt track is extremely delicate and prone to collapse, especially at lower leaning angles. However, says Skalon, the modified steel particles are able to support the melt track so that it remains stable, even at low leaning angles (Figure 3). "The particles' surfaces are modified so they interact in a smarter way with the molten metal," he adds. Furthermore, by making steel powders more readily printed, less materials are wasted and any surplus steel powders can be recycled at the end of the process. So far, Skalon's steel modifications have focused on 316L stainless steel, but there are plans to apply the work to other steel grades as well. The modification technology currently runs at laboratory scale, and within 2–3 months, Skalon expects an industrial-scale demonstration, with commercial-ready products reaching the market in 2020. The modified steel powders are particularly applicable for topology-optimized parts, low-angle lattice structures and advanced piping and valve systems, such as those used in flow-chemistry processes.

Diamond. Earlier this year, Sandvik Additive Manufacturing (www.additive.sandvik.com) unveiled a 3D-printed diamond nanocomposite — said to be the world's first. The 3D-printed diamond nanocomposite was created via stereolithography (SLA) using a slurry containing diamond powder and a polymer. The ability to 3D print with diamond paves the way for widespread adoption of customized, complex parts with the unrivaled hardness and other desirable properties that diamond possesses. "Being able to integrate the hardest naturally occurring material on the planet into additive manufacturing would drastically improve product properties, including increasing resilience, corrosion resistance and conductivity, as well as making parts significantly lighter," explains Anders Ohlsson, delivery manager at Sandvik Additive Manufacturing. "Furthermore," continues Ohlsson, "Sandvik's method of producing composite diamond also produces a low amount of waste because excess materials can be recycled for future use." To imbue the printed diamond part with its signature hardness, Sandvik has developed a proprietary post-processing step. "The composite is three times stiffer than steel, with heat conductivity higher than copper and a density close to aluminum," adds Ohlsson. A diverse array of industries could benefit from 3D printing with diamond, from power generation to mining to medical implants. Although the diamond nanocomposite is still in the demonstration phase, many end-use applications are currently undergoing trials, according to Ohlsson.

Graphene. A collaboration between GrapheneCA (Montreal, Que., Canada; www.grapheneca.com) and Apis Cor (Boston, Mass.; www.apis-cor.com) brings together two world-first technologies — modular, scalable graphene production and mega-scale 3D printing for construction applications — with the aim of creating an ultra-large-format 3D printing system that can handle graphene materials (Figure 4). "In 3D printing, graphene acts as a multi-tasking additive. Using graphene, you can impart a number of mechanical attributes to most materials, and it is also possible to achieve properties like conductivity, heat dispersion and controlled permeability," says David Robles, head of business development at GrapheneCA. This means that graphene can provide most of the functionality of several other additives in a single material, which leads to simpler, faster production. Additionally, explains Sergey Voskresensky, head of R&D at GrapheneCA, because graphene is chemically inert, it does not interact with glues and can act as a secondary matrix within printed media. GrapheneCA has developed mobile graphene container systems (MGCS) that can produce four tons per month of dry-weight graphene using a straightforward water-exfoliation process.

GrapheneCA's team is currently designing a specialized mixer and extruder system, along with new printer heads, for graphene compatibility with Apis Cor's newest 3D printer. For 3D-printing applications, mixing is especially crucial, because graphene has the tendency to settle into low-viscosity media and an even dispersion must be maintained. However, GrapheneCA has addressed these concerns with its graphene-geopolymer composites, in which the graphene is mixed and made, and can be produced on location, alleviating settling and agglomeration issues with aqueous inks.

Apis Cor's modular printing systems are tailored for very large construction projects, including barges, warehouses, pipelines, storage tanks and more. "This is one of the only 3D printers of its size that isn't stationary," says Robles. The printing capacity is around 2,500 ft^2 of material in 24 hours, for structures up to 20 ft tall. The ability to incorporate graphene-based materials into these printers will expand the application areas, as well as the robustness of final printed structures, such as printed buildings that can withstand extreme weather

conditions. "Right now, we are looking into how to make locally producible inks for the printer and new nozzles that will make these printers an ideal building solution," adds Voskresensky. "Our process equals a high-quality, longer-lasting build that requires less labor and materials."

More materials innovations. Some highlights of additional innovative projects in the area of 3D-printing materials are summarized below:

- Oak Ridge National Laboratory (Oak Ridge, Tenn.; www.ornl.gov) has developed a patent-pending renewable composite of lignin and nylon for 3D printing
- HRL Laboratories, LLC (Malibu, Calif.; www.hrl.com) is commercializing a high-strength aluminum powder for 3D printing and has become the first organization to be granted an alloy registration number for an AM material by the Aluminum Association
- Evonik Industries AG (Essen, Germany; www.evonik.com) developed the industry's first 3D-printing polymer filament based on PEEK (polyether ether ketone) that is suitable for use in medical implants
- Clariant AG (Muttenz, Switzerland; www.clariant.com) offers glass-fiber-filled, flame-retardant polyamide 6 3D-printing filament materials that meet UL 94 Flammability Safety Standards
- Wacker Chemie AG (Munich, Germany; www.wacker.com) has developed a proprietary 3D-printing process specifically for silicone rubbers. The newest version can print up to four different silicone materials simultaneously
- Late last year, Arkema (Colombes, France; www.arkema.com) introduced a new polyetherketoneketone (PEKK) masterbatch with multi-wall carbon nanotubes for filament printing applications

CPI investment spurs innovation

The advantages of AM to the CPI are multifaceted — in many cases, the companies that benefit from rapid manufacture of spare or customized parts may also themselves produce advanced materials that can be used in AM processes. This synergy has

GrapheneCA

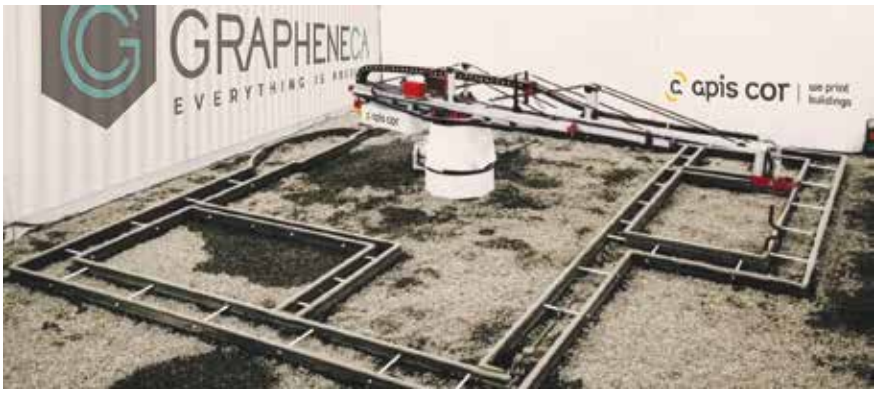


FIGURE 4. Incorporating graphene materials into mega-scale 3D printing involves the development of specialized nozzles and mixing sytems

spurred significant collaboration.

For instance, BASF SE (Ludwigshafen, Germany; www.basf.com) recently invested in China-based AM technology provider Prismlab, with the aim of tackling new 3D-printing applications, particularly in areas where mass production and precise materials specifications are required. Prismlab has developed a SLA-based 3D-printing process known as Pixel Resolution Enhanced Technology wherein a pixel is divided into several parts. These parts are individually cured via exposure to an LCD light, resulting in higher energy input into each pixel, and ultimately, higher printing resolution without printing speed losses. This yields hardened parts that are more stable and homogenous, enabling larger parts to be printed than with conventional SLA processes, and even for multiple components to be printed in a single step. Furthermore, the use of an LCD light source rather than a laser reduces equipment and energy costs. Prismlab uses an LCD light source that allows printing on the surface level, which significantly increases the total output, says BASF.

In July, Covestro AG (Leverkusen, Germany; www.covestro.com) announced a partnership with Carbon, Inc. (Redwood City, Calif.; www.carbon3d.com), the developer of the ultra-fast AM method known as Digital Light Synthesis (DLS). DLS is said to produce parts up to 100 times faster than typical SLA processes. Covestro is researching materials to complement DLS and aiding in scaleup of DLS for mass production. Similar to other AM methods, DLS begins with a liquid resin that is cured with ultraviolet light. The resin is contained within a vessel whose bottom is a light- and air-permeable membrane through which oxygen is supplied to counteract the curing, creating a functional dead zone and enabling the printed part to be continuously pulled upward. This results in high levels of consistency in all directions and enables DLS to effectively utilize a wide swath of materials.

At the 2019 RAPID + TCT conference, Dow Chemical (Midland, Mich.; www.dow.com) joined forces with AM specialists German RepRap GmbH (Feldkirchen, Germany; www.germanreprap.com) and RDAbbott (Cerritos, Calif.; www.rdabbott.com) to demonstrate the capabilities of liquid additive manufacturing (LAM) with liquid silicone rubber. GermanRepRap has developed the world's first production-ready LAM printer. LAM with silicone enables printing of complex geometric shapes, including lattice and honeycomb structures.

Earlier this year, Evonik and Evolve Additive Solutions Inc. (Minnetonka, Minn.; www.evolveadditive.com) partnered to develop polyamide materials for use with Evolve's proprietary AM technology, selective thermoplastic electrophotographic process (STEP). The STEP process is expected to reach commercialization in late 2020.

Henkel AG & Co. KGaA (Dusseldorf, Germany; www.henkel.com) has joined a German-Austrian consortium known as SYMPA aimed at advancing materials and applications for SLA products using Digital Light Processing (DLP). ■

Mary Page Bailey

Driving Toward a Hydrogen-based Economy

Technology developments are progressing towards large-scale production of 'green' hydrogen, along with improved methods for storage and transportation

The world has an important opportunity to tap into hydrogen's vast potential to become a critical part of a more sustainable and secure energy future," according to an in-depth study launched by the International Energy Agency (IEA; Paris, France; www.iea.org) on the occasion of the meeting of G20 energy and environment ministers in Karuizawa, Japan, on June 15–16. "Clean hydrogen is currently receiving strong support from government and businesses around the world, with the number of policies and projects expanding rapidly," the study says. Titled The Future of Hydrogen: Seizing Today's Opportunities, and launched by the IEA's executive director Fatih Birol, and Japan's minister of economy, trade and industry Hiroshige Seko, the study says hydrogen offers ways to decarbonize a range of sectors, including chemicals manufacturing and iron and steel production, and it can be transformed into fuels for cars, trucks, trains, ships and aircraft. "The world should not miss this unique chance to make hydrogen an important part of our clean and secure energy future," Birol says.

There are, however, people who believe H_2 fuel cells will never be widely used, because they present high costs and low efficiencies when compared with batteries, such as lithium-ion batteries (LIBs), and it would take too long to overcome the technical issues involved. Nevertheless, efforts are ongoing to improve the technology and economics of a hydrogen-based economy.

H_2 for transportation

As a fuel system for cars, buses, trains and so on, hydrogen is stored in a tank within the vehicle. H_2 is fed to a fuel cell, which produces electricity for an electric motor that moves the vehicle. Unlike fossil fuels, hydrogen combustion produces no CO_2 or other pollutants — just water vapor.

As far as a fuel system for motor cars is concerned, the main contender of H_2 fuel cells is LIBs. Today most electric vehicles use batteries, often based on Li-ion or lead-acid chemistry. Each individual fuel cell produces low currents and voltages and, like LIBs, the cells need to be stacked together to reach the target voltage and maximum current required by the vehicle.

Hyundai

FIGURE 1. One of the latest hydrogen-fueled automobiles is the Hyundai Nexo

One of the advantages of H_2 used in fuel cells is that it has an energy-to-weight ratio (specific energy) much greater than that of LIBs. The specific energy of LIBs is 0.36 to 0.875 MJ/kg, and the specific energy of hydrogen is 120 to 142 MJ/kg. H_2 in fuel cells thus permits much greater range while being lighter and occupying smaller volumes. Another major advantage of H_2 fuel cells is that they can be recharged in a few minutes. In contrast, full charge times for LIB electric vehicles is typically measured in hours.

However, H_2 also entails serious drawbacks. One of them is that it combines well with other elements and therefore has to be isolated, before being usable as fuel, by means of processes that are expensive and energy consuming. Also, storing H_2 is expensive and energy intensive, either when it is stored as a gas at high pressure, or even more so, as a liquid at cryogenic temperatures. H_2, which is also highly flammable, is difficult, dangerous and expensive to produce, store and transport.

In spite of the problems presented by H_2 fuel cells, and in spite of the negative predictions by some experts, a large number of projects are ongoing and a significant amount of R&D dollars are being invested in H_2 fuel cells around the world. There are already many vehicles running on hydrogen fuel cells, including motor cars, buses and trains, although they have not yet attained wide market acceptance. According to the IEA, there are currently about 11,200 H_2-powered cars on the roads worldwide.

The oldest hydrogen cars commercially available in selected markets are: the Toyota Mirai, the Hyundai Nexo and the Honda Clarity. In 2013 the Hyundai Tucson fuel-cell electric vehicle (FCEV) was the first commercially mass-produced H_2 FCEV in the world. It had a range of nearly 600 km. Hyundai Nexo (Figure 1) succeeded it in 2018. Toyota launched its Mirai at the end of 2014. It has a range of about 500 km and it takes about 5 min to refill its H_2 tank.

Although many automobile companies have introduced demonstration models in limited numbers, many

Alstrom

FIGURE 2. The world's first hydrogen-fueled passenger train started operating last September in Lower Saxony, Germany

of those companies have switched to battery electric vehicles.

Late last year, the world's first passenger train powered by H_2 fuel cells began operating in Germany (Figure 2). Called Coradia iLint, it was developed by Alstom (Paris, France; www.alstom.com). The train is capable of maximum speeds of 140 km/h.

H_2 production

Currently, almost all of the world's H_2 is supplied from fossil feedstocks in processes that emit CO_2, unless the CO_2 is adequately captured and stored. Clean H_2 production is achieved by the electrolysis of water using electricity obtained from renewable sources, such as solar and wind. Presently, however, only about 5% of the world's H_2 is produced via water splitting. The process within the fuel cell is essentially the reverse of the electrolytic process for producing H_2 from water. In the H_2 fuel cell, the H_2 reacts with oxygen from the air, and the only byproduct is clean water.

Recently, thyssenkrupp AG (Essen, Germany; www.thyssenkrupp.com; Figure 3) and Siemens AG (Erlangen, Germany; www.siemens.com) have developed new, large-scale electrolyzers in order to decarbonize the production of H_2 (*Chem. Eng.*, January 2019, pp. 14–17).

Siemens' electrolyzers were initially capable of turning kilowatts of renewable energy into clean H_2, and the company is now building larger scale devices. Siemens will soon deliver a 1.25-MW unit to the Tonsley Innovation District of South Australia. It is also offering a unit capable of scaling up to 10 MW, with plans to scale further by another order of magnitude.

The largest solar-powered green hydrogen plant in the world is planned for the Burrup Peninsula in Western Australia by Yara Pilbara (Burrup, Western Australia; www.yara.com.au) and French energy company Engie (Paris, France; www.engie.com). It will be a full-scale 100-MW plant with a 66-MW electrolyzer.

In January, Air Liquide (Paris, France; www.airliquide.com) invested $20 million in Hydrogenics Corp. (Mississauga, Ontario; www.hydrogenics.com), a leader in electrolysis H_2 production equipment and fuel cells. Air Liquide and Hydrogenics have also entered into a technology and commercial agreement to jointly develop proton exchange membrane (PEM) electrolysis technologies for the rapidly growing H_2 energy markets around the world.

Meanwhile, Angstrom Advanced, Inc. (Stoughton, Mass.; www.verdellc.com), which offers renewable H_2-generation systems, says the state government of Massachusetts confirmed, in 2016, that the world's first commercialized renewable energy H_2 production, stor-

age, refueling, and fuel cell microgrid demonstration project would be operated by the company in the Boston area. More recently, the company has developed what it claims to be the world's first all-in-one H_2 refueler.

Last October, a Japanese consortium started construction of the Fukushima Hydrogen Energy Research Field (FH2R; *Chem. Eng.*, October 2018, p. 10). FH2R will produce (using renewable energy) and store up to 900 ton/yr of H_2. It will use a new control system to coordinate overall operation of the H_2 energy system, the power grid control system, and the H_2-demand-forecast system, so as to optimize H_2 production, H_2-based electricity generation and H_2 gas supply.

The system will use H_2 to offset grid loads, and deliver H_2 to locations in Tohoku and beyond, and will seek to demonstrate the advantages of H_2 as a solution in grid balancing and as a H_2 gas supply. Compressed H_2 will be transported in trailers and supplied to users.

H_2-production research

The U.S. Dept. of Energy (DOE; Washington, D.C.; www.energy.gov) Hydrogen and Fuel Cell Program conducts research and development in H_2 production, delivery, storage and fuel cells. Its technical targets are: biomass-derived liquid reforming, electrolysis, biomass gasification, thermochemical water splitting, photoelectrochemical water splitting, photobiological processes, and microbial biomass conversion.

Meanwhile, research is being conducted at a water purification plant in Sendai, Miyagi Prefecture, Japan to incorporate H_2 into renewable energy systems. The city of Fukuoka is engaged in a project to produce H_2 with biogas extracted from sewage sludge. The H_2 produced will be used for fuel cell vehicles.

"Sewage treatment plants across the nation have the potential to power up to 1.86 million fuel cell vehicles with hydrogen," says Masaki Tajima, a professor of environmental energy at Tottori University (Tottori City, Japan; www.tottori-u.ac.jp).

Also in Japan, Toshiba Corp. (Tokyo; www.toshiba.com) has developed its 100-kW H2Rex pure hydrogen cascading fuel cells, which increases the utilization rate of hydrogen. The fuel cells can generate power at a temperature of 80°C, which is much lower than the operating temperature of other types of fuel cells, eliminating the need for a heating process.

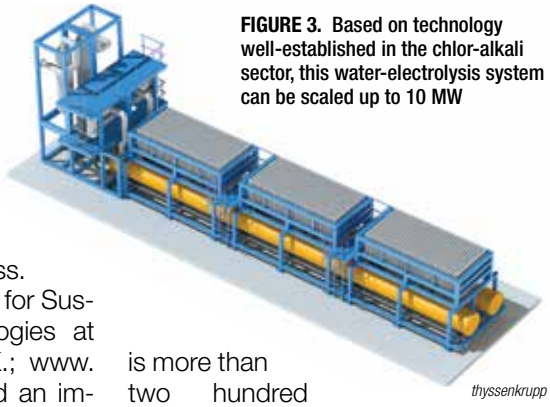
Researchers at the Center for Sustainable Chemical Technologies at the University of Bath (U.K.; www.bath.ac.uk), have developed an improved method for using sunlight to split water. They used perovskite solar cells. Since these cells are unstable in water, which limits their use for the direct generation of clean H_2 fuels, the researchers used a waterproof coating from graphite. While perovskite solar cells produce a higher voltage than silicon cells, the voltage is still not enough to split water. To solve this problem, the researchers added catalysts.

Another way to boost H_2 production from electrolysis has been recently discovered by a team from the Institute of Chemical Research of Catalonia (Tarragona, Spain; www.iciq.org), led by José Ramón Galón-Mascarós. The researchers achieved H_2 production at low voltages just by approaching a permanent magnet to the anode, which results in immediate energy savings.

The team also used catalysts based on earth-abundant metals like nickel and iron. The team claims it can increase the H_2-producing efficiency using an electrolyzer by 100%. In an industrial setting the team would expect efficiency gains of 30 to 40% (*Chem. Eng.*, July 2019, p. 12).

Researchers at the Indian Institute of Science (Bengaluru, India; www.iisc.ac.in), led by professor Prabeer Barpanda, have developed a low-cost catalyst to speed up the splitting of water to produce H_2.

One of the two major reactions involved in this process — the oxygen evolution reaction — is slow, limiting the process' overall efficiency. The most efficient catalysts normally used are made of expensive metals, such as Pt and Ru. The Indian researchers have developed a catalyst by combining cobalt oxide with phosphate salts of sodium (metaphosphates). The researchers claim this catalyst is more than two hundred times less expensive than the current state-of-the-art RuO_2 catalyst, and the reaction rate is also faster.



thyssenkrupp

FIGURE 3. Based on technology well-established in the chlor-alkali sector, this water-electrolysis system can be scaled up to 10 MW

To make the catalyst, the researchers roasted sodium metaphosphate and cobalt oxide in an argon atmosphere. This creates a sheet of partially burned carbon onto which crystals made of cobalt oxide framed by sodium metaphosphate are spread out. The metaphosphates form a strong framework to hold the cobalt oxides intact, showing high stability. This treatment allows the catalyst to retain its activity over multiple cycles.

H_2-storage research

A team from the University of Michigan (Ann Arbor; www.umich.edu), led by professor Don Siegel, has identified ways to cram more H_2 than ever before into metal-organic frameworks (MOFs), increasing the energy density, and therefore the projected driving range of fuel cell vehicles.

The team created a database on MOFs, and used computer simulations to screen nearly 500,000 MOFs for those best suited to store H_2. Three MOFs were identified that would surpass previous records for H_2 storage. Siegel says that by increasing the quantity of H_2 that can be stored in a MOF adsorbent, the pressure needed to store it can be reduced, and the size of the tank can also be reduced.

In another way to store and transport H_2, Chiyoda Corp. (Yokohama, Japan; www.chiyodacorp.com), in association with JXTG Nippon Oil & Energy Corp., the University of Tokyo and Queensland University of Technology, has developed the SPERA Hydrogen system. This system is kept in a liquid state at ambient temperatures and pressures, and can therefore be stored in existing tanks for a long time and transported by existing tankers.

The system is a liquid called methylcyclohexane (MCH). It is produced using the organic chemical hydride (OCH) method, whereby toluene and hydrogen are catalytically reacted. The volume of MCH is a small fraction of the volume of gaseous H_2.

Although the OCH method using MCH has been known for a long time, no commercial catalyst has been developed for producing H_2 from MCH in the dehydrogenation process. Chiyoda developed a dehydrogenation catalyst that continuously delivers stable high performance for more than 10,000 h at the laboratory scale.

In yet another approach, a team from the University of Newcastle (Newcastle-upon-Tyne, U.K.; www.ncl.ac.uk), led by professor Ian Metcalfe, has developed what it claims is the first thermodynamically reversible chemical reactor capable of producing H_2 as a pure product stream.

The reactor avoids mixing reactant gases by transferring oxygen between reactant streams via a solid-sate oxygen reservoir. The reservoir is designed to remain close to equilibrium with the reacting gas streams as they follow their reaction trajectory and thus retains a "chemical memory" of the conditions to which it was exposed. The H_2 is thus produced as a pure product stream, eliminating the need for costly separation of the final products. "Whereas conventional H_2 production requires two reactors and a separation, our reactor accomplishes all the steps in one unit," Metcalfe says.

Researchers from Pohang University of Science and Technology (Pohang, South Korea; www.postech.ac.kr) and the Colorado School of Mines (Golden, Colorado; www.mines.edu), led by Pohang's Kun-Hong Lee and Bo Ram Lee, have introduced a new concept for improving hydrogen storage capacity inside the structure formed by water molecules called gas hydrates.

Gas hydrates are ice-like solid compounds including gas. The main problem in storing hydrogen in gas hydrates has been lowering the energy required. The researchers studied the metastability of gas hydrates, which is determined by a stable state that can be changed by the addition of a small amount of energy. They succeeded to keep the hydrogen hydrates stable at very mild pressure (0.5 to 1MPa) and demonstrated increased H_2 storage in the hydrates (up to 52% larger amount).

"If an appropriate process is designed to trap the system in this metastable state with a high concentration of gas, coupled with the benefits of hydrate self-preservation, a new paradigm will be born for gas storage in clathrate hydrates," says Kun-Hong Lee.

Meanwhile, the CSIRO (Melbourne, Australia; www.csiro.au) has conducted a study on the "Round-trip Efficiency of Ammonia as a Renewable Energy Transportation Medium." The study says that NH_3 is an excellent proposition for converting renewable energy to H_2, transporting it to locations with low renewable energy intensity and converting the NH_3 back to H_2 for local consumption. The round-trip efficiency of electrical energy storage can be higher than 80%, the study says. ■

Paul Grad

Laboratory Measurements Aid Process Efficiency

New laboratory instruments simplify the collection of accurate and consistent measurements to increase productivity and product quality

IN BRIEF

FASTER, REPEATABLE RESULTS

EASE OF USE

INCREASED CAPABILITIES

Efficiency and optimization are key words when it comes to all aspects of chemical processing and the laboratory is no different. Like most operations within a chemical facility, the laboratory is also tasked with streamlining operations, which means using instruments that achieve high productivity and can more easily collect accurate and consistent measurements in an effort to ensure that raw materials, intermediates and finished products all meet critical quality and safety attributes.

MKS

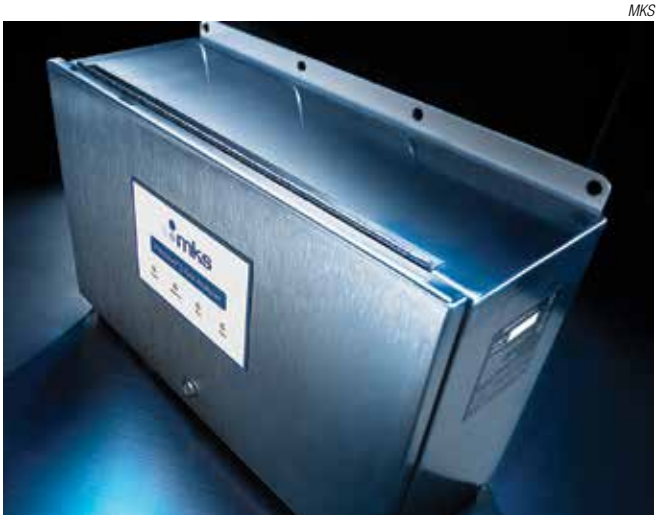


FIGURE 1. The Precisive 5 Hydrocarbon Composition Analyzer uses a new non-dispersive infrared (NDIR) platform based on tunable filter spectroscopy, enabling complex measurements to be performed with low-cost and rugged NDIR-based instruments

"One of the biggest challenges in the chemical industry is ensuring that laboratory technicians and operators are confident that they can rely on the equipment they use," says Ricki Hartwell, senior product manager, water and laboratory products with Thermo Fisher Scientific (Waltham, Mass.; www.thermofisher.com). "Time and again, ease of use and sample compatibility are cited as two of the most important considerations when selecting laboratory instruments. Laboratory managers and technicians expect that their equipment will make achieving accurate, precise and reproducible measurements intuitive."

And, providers of laboratory instruments have responded by developing user-friendly systems that make it as easy as possible for laboratory teams to generate and access the high-quality results they need, according to the experts.

Faster, repeatable results

Many processes today involve fast dynamics, which need to be captured, says Vidi Saptari, general manager for process and environmental analysis solutions with MKS Instruments, Inc. (Andover, Mass.; www.mksinst.com). "Therefore, one of the challenges is being able to provide sub-second measurement while maintaining high sensitivity and accuracy. Trade-offs between fast response and sensitivity are generally present, and, as such, careful optimization of the instrument needs to be performed."

For this reason, MKS specializes in infrared-based gas analyzers used in applications requiring continuous and realtime measurements that replace or augment traditional laboratory instruments using batch processing methods. "Optics-based technologies provide a versatile platform to be optimized for various applications," says Saptari.

As such, the company recently introduced The Precisive 5 Hydrocarbon Composition Analyzer (Figure 1), which is an infrared (IR) absorption-based on-line monitoring system configured for measurement of alkanes, such as methane, ethane, propane, butanes and pentanes. It uses a new non-dispersive infrared (NDIR) platform based on tunable filter spectroscopy that enables

Hiden Isochema

FIGURE 2. The integral mass balance method (IMB) for measuring multi-component gas adsorption is featured in the IGA-003-MC gravimetric sorption analyzer. The IMB method allows the rapid, accurate measurement of binary gas-adsorption isotherms on relatively small samples of only a few grams

LECO

FIGURE 3. The TGA801 thermogravimetric analyzer provides accurate, high-precision thermogravimetric constituent analysis of various organic, inorganic and synthetic materials

complex measurements to be performed with low-cost and rugged NDIR-based instruments, which could previously only be performed by Fourier-transform IR (FTIR) analyzers or gas chromatographs.

"Users benefit from accurate and realtime information, in addition to significantly lowered costs of operation," says Saptari. "In some cases, they become the enabling technologies to perform closed-loop control of the process, thus improving product quality and reducing yield and waste."

When it comes to obtaining gravimetric gas and vapor sorption measurements, which are used for the design and development of gas-separation and purification processes, achieving high accuracy can be a challenge because results can be affected by the way the material is prepared for the measurement, by impurities in the gas or vapor supply and by temperature measurement accuracy and stability, says Darren Broom, product manager with Hiden Isochema Ltd. (Warrington, U.K.; www.hidenisochema.com). "Measurements can also be rather time consuming, particularly if the sorption kinetics — the rate at which the gas or vapor adsorbs — are slow. Therefore, speeding up the process while maintaining high accuracy is one of the most significant challenges for pure-gas sorption measurements. For this reason, chemical engineers require methods of quickly and easily measuring gas and vapor sorption, so increasing sample throughput is highly desirable."

The company recently introduced the Integral Mass Balance (IMB) method for measuring multi-component gas adsorption, which is featured in the IGA-003-MC gravimetric sorption analyzer (Figure 2). "Measuring multi-component gas adsorption continues to be a challenge, even though such data are critical to the development and design of gas separation and purification processes. The IMB method allows the rapid, accurate measurement of binary gas-adsorption isotherms on relatively small samples of only a few grams," says Broom.

There are similar needs for faster, more repeatable results required of equipment such as combustion-based carbon, hydrogen, nitrogen, sulfur and oxygen elemental instruments, macro thermogravimetric analyzers (Macro TGA) and mass spectrometry instruments, says Mason Marsh, organic product manager with LECO Corp. (St. Joseph, Mich.; www.leco.com). "Sample collection and subsequent preparation for the various materials can be a challenge, as the instruments will typically require sample mass from a few tenths of a gram up to one gram. Viscous materials require heating and mixing, while solid materials will require grinding the material to a particle size (typically in the 250 µm range)," says Marsh. "Further, users will typically have precision requirements that are specified in terms of repeatability and reproducibility of results tied to specific test methods."

Macro thermogravimetric analysis can be used to replace the often slow, labor-intensive, traditional manual gravimetric techniques that require multiple sample weighing and transfer steps involving ovens, muffle furnaces and desiccator equipment. So, the company recently released the TGA801 thermogravimetric analyzer (Figure 3), which incorporates state-of-the art hardware with an onboard touch-screen software platform to provide accurate, high-precision thermogravimetric constituent analysis — moisture, ash, volatile content and loss of ignition (LOI) in various organic, inorganic and synthetic materials.

The instrument helps maximize productivity and improve work flow by offering automated thermogravimetric analysis for batches of up to 19 samples, eliminating the

Thermo Fisher Scientific

FIGURE 4. The Orion Star T910 pH Titrator features a large display that provides on-screen prompts to guide operators through workflows

handling, transfer and cooling time required of traditional gravimetric methods and optimizing analysis time by using automatic end point recognition based upon sample mass constancy.

Ease of use

Part of achieving faster, more accurate and repeatable results comes from designing easier-to-use equipment. "Robustness and usability are central to the design of our products, helping users achieve accurate, reliable and reproducible analyses in high-throughput environments," says Thermo Fisher Scientific's Hartwell.

Ajay Badhwar, business director, oil-and-gas chemicals with Thermo Fisher Scientific, agrees and adds: "Instrument ease of use and flexibility are key requirements in many analytical laboratories, but this is especially important in the chemical industry, where experiments are not only performed in high-performance R&D laboratories, but also in more challenging QA/QC locations, such as production and storage areas."

The company's Orion Star T910 pH Titrator (Figure 4) features a large, color touch-screen display that provides on-screen prompts to guide operators through workflows. Automating manual titrations can help improve testing by simplifying the testing process and delivering accurate and reliable results with less hands-on time required.

Weighing equipment and balances are also getting a much-needed revamp to make them more user friendly. "Formulations could consist of 30 or more separate components, and the formulation process itself can be labor intensive and require concentration. Even the most skilled technician might spend over an hour and a half preparing certain mixtures," says a representative with Mettler-Toledo (Columbus, Ohio; www.mt.com). "In addition, to ensure complete traceability, information crucial to the process must be recorded, such as the user ID, recipe, name, date and time of preparation, expiration date, batch number, compounds used, quantities required, tolerances and quantities dispensed. This will often take the form of handwritten component labels and laboratory notebook records, in addition to instrument printouts of weights. This process is time-consuming and prone to human error, potentially resulting in formulations having to be repeated."

Regardless of the laboratory hardware used, there are several factors that can influence the weighing, such as air currents, electrostatic charges and magnetic stirrers. These can give rise to issues such as difficulty taring the balance, drifting and unstable readings, longer settling times and poor weighing accuracy, which may reduce productivity and require formulation to be repeated. Draft shields are often used to protect the weighing pan and the tare container from the influence of air currents, particularly within fume hoods or safety cabinets, but these also have drawbacks.

To make weighing easier and faster, Mettler Toledo offers balances equipped with a SmartPan weighing pan, such as the XPR balance range (Figure 5), which enables precision weighing with the minimum of fuss, even in the presence of air currents. Stabilization times are up to twice as fast, and up to a two-fold improvement in repeatability can be seen. There is no need for a draft shield, even when weighing

Mettler-Toledo

FIGURE 5. Balances equipped with a SmartPan weighing pan, such as the XPR balance range, enable precision weighing, even in the presence of air currents

in a fume hood, making weighing easier and more ergonomic, saving an estimated eight to ten seconds per component weighed.

Increased capabilities

Another oft-cited instrumentation requirement is doing more analysis within an existing footprint, says Thermo Fisher Scientific's Badhwar. "It's not always feasible to build another lab or another central research group, so they often must run instruments harder or find ways to de-bottleneck [laboratory] operations. Additionally, not only are EH&S [environmental, health and safety] requirements changing, but the demands of analytical test methods are also evolving."

One of the ways this is being addressed is by designing instruments that are capable of performing more functions for higher throughput in the existing laboratory. For example, the Thermo Scientific Vanquish Duo UHPLC system offers two flow paths in a single integrated system to increase throughput and minimize laboratory footprint. The flexibility offered by the system supports tandem liquid chromatography or liquid chromatography mass spectrometry workflows that optimize the use of, and increase return on investment for, detectors and mass spectrometers.

Ametek Brookfield (Middleboro, Mass.; www.brookfieldengineering.com) recently launched its new RSO air bearing oscillatory rheometer, used for studying flow in pumping, mixing, blending, spraying, printing, painting and coating system designs and for gaining knowledge of a product's viscosity. The advance is that the instrument provides both rotational and oscillatory shear capability with moderate temperature control range in a small footprint. "There are a significant number of simple tests that can be run in standalone mode without even needing a computer," says Dave Moonay, quality engineer — rheologist, with Ametek Brookfield. "This allows a relatively quick, but thorough overview of the sample's rheological behavior, making it a very useful tool for chemical processors."

In rotational test mode, the operator may enter torque setting, stress or speed or shear rate. There is also a built-in test mode for viscosity, yield testing, creep recovery and thixotropy. Under oscillatory test mode, there are amplitude sweeps, stress or strain tests, as well as sweeps that will test time dependence. Temperature-dependent tests that look at material behaviors at different temperatures are also possible.

The need to do more with one unit is no different when it comes to particle characterization instruments, says James Pastore, customer application specialist with Microtrac (Montgomeryville, Pa.; www.microtrac.com). The company offers the Sync, a synchronous size and shape particle analyzer (Figure 6) that integrates laser-diffraction technology with dynamic-image analysis technology, allowing users to get particle-size distribution together with particle morphology in a single, easy-to-use graphical user interface.

The Sync interrogates particles, wet or dry, with laser light while simultaneously a high-speed digital camera takes images. The data collected are processed by software and present the user with particle size and shape information from one instrument. ■

Joy LePree

Microtrac

FIGURE 6. The Sync synchronous size and shape particle analyzer integrates laser diffraction technology with dynamic image analysis technology, allowing users to get particle-size distribution together with particle morphology in a single graphical user interface

Mobile Engineering Apps

A mobile app to access on-demand fan information

This fan and blower manufacturer has introduced a mobile app (photo) to help users find information about their fans and order replacement parts. Using the app, users can access fan information on-demand, calculate changes in operating conditions and connect with their local sales representative from a mobile device. Those who have ordered fans since January 2000 can use the app's search function to quickly collect information specific to a fan with a shop or fan serial number, without returning to a computer or calling a sales representative. The app houses product manuals, specifications, model information, product drawings, curves, wheel type, impeller type, original operating conditions and more. Engineers and operations managers can save previous searches and label fans according to an application or the fan's location for future reference, storing all this company's fan information in one place. — *The New York Blower Co., Willowbrook, Ill.*
www.nyb.com

A cloud-based web app for monitoring applications

An enhanced version of this company's cloud-based web application was introduced recently. The app enables users to access realtime and logged data from any of the company's WiFi-enabled AdvancedSense meters, WolfPack monitors or WolfSense LAP tablet-based kits. In addition, the company's DirectSense II probes will soon offer an optional, installed WiFi card allowing for direct communication to most internet-connected devices via GrayWolfLive 3.0 (photo). — *GrayWolf Sensing Solutions, Shelton Conn.*
www.graywolfsensing.com

A calculator for installing pipe-penetration seals

Launched in January, the Pen-Seal Calculator is a useful tool to help aid in the proper selection and installation (photo) of pipe-penetration seals (Pen-Seals) into a piping system. The Pen-Seal Calculator is designed to assist in selecting the correct number of links and the correct size of link for pipe penetrations passing through walls or floors. To achieve a 100% water- or gas-tight seal, enter in the pipe O.D. and the penetration I.D. to provide the required size/link combination. The standard elastomer for the Pen-Seal is ethylene propylene diene monomer rubber (EPDM), and can be used in various applications in power generation, water and wastewater, mining and heating, ventilation, and air conditioning (HVAC) applications. The Calculator is available for both iOS and Android. — *Proco Products, Inc., Stockton, Calif.*
www.procoproducts.com

Perform simulations on-the-go with an Android device

Launched in April, the COMSOL Client for Android (photo) enables researchers and engineers to perform simulations from their Android devices, such as phones, tablets and Chromebooks simply by connecting to the COMSOL Server software, which runs the computations remotely. The Client expands on the capabilities of the Application Builder and COMSOL Server by enabling users to take their simulation applications on the road, without being limited by device hardware. Providing field technicians or sales representatives with the power of COMSOL Multiphysics directly on their Android devices allows them to bring the R&D work on site. The Application Builder and COMSOL Server were developed to make multiphysics modeling more accessible to a wider audience. The Application Builder allows simulation specialists to create custom-made applications based on their multiphysics models. — *Comsol, Inc., Burlington, Mass.*
www.comsol.com

Bringing remote worker back into the office — digitally

A combination of this company's information gathering and analyti-

The New York Blower Co.

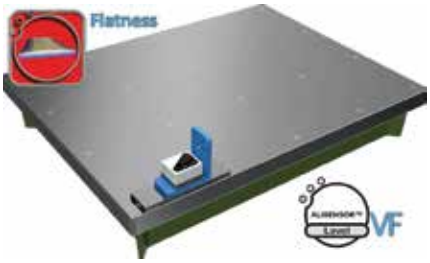
GrayWolf Sensing Solutions

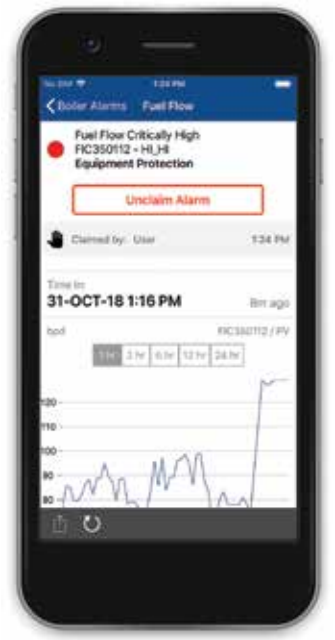
Proco Products

Comsol

Note: For more information, circle the 3-digit number on p. 70, or use the website designation.

Alignment Supplies





Emerson

Omega Engineering

cal capabilities and Garmin's 790 telematics tablet has closed the gap between head office and operations in the field. Improved awareness of business operations and significantly upgraded capabilities around worker safety are helping managers make informed realtime decisions. Operating on the open-source Android platform, the Garmin 790 integrates seamlessly with many existing mobile field-force-management programs, providing the platform for online job sheets, reporting, time sheets and more via customized apps. — *Smartrak, Melbourne, Australia*
www.smartrak.com

A flatness app for this level-measurement system

The release of Flatness for the ALiSensor Level (photo) is the latest app for the ALiSensor Level geometric measurement system. Flatness is a geometric measurement that is often required, but has been rather cost-prohibitive with laser-based geometry systems, says the company. The new app makes precision flatness measurements "extraordinarily cost-effective and extremely easy to perform," the company adds. The Flatness measurement program App enables users to measure the flatness of surfaces of a wide range of shapes and sizes through the ability of the ALiSensor Level to be calibrated to user-made fixtures of all sizes. The ability to customize the number of measurement points along both axes also enables users to perform very detailed and thorough flatness measurements, while also equipping them with the ability to customize the number of measurement points for specific applications, such as performing a flatness measurement on two rails for a motor or pump installation. — *Alignment Supplies, Inc., Maumee, Ohio*
www.alignmentsupplies.com

Calculate fluid mechanics with this new app

This company adds to its extensive range of apps and online tools with the introduction of the Fluid Mechanics Calculator App. Free of charge to download, the app boasts more content, formulas and calculations than other similar paid-for tools. The new app covers a wide variety of topics in the field of fluid mechanics and serves as a reference for the analysis, design, maintenance and operation of fluid-related systems. It provides results for different fluid-mechanics equations, including those used in civil, structural, pipe flow and general engineering. The Fluid Mechanics Calculator has over 130 formulas and more than 360 different calculations. The app can be downloaded for iPhone or Android. — *Trelleborg Sealing Solutions, Stockholm, Sweden*
www.trelleborg.com

Mobile app upgrades access to critical data

This company has enhanced its DeltaV Mobile app (photo) to ensure plant personnel have faster access to process information and to help organizations tailor the notifications personnel receive. DeltaV Mobile — a mobile app that provides read-only access to a plant's distributed control system and operation data — now offers improved customization and access to third-party systems in one app. DeltaV Mobile users will be able to more quickly respond to important process information and changes, including held batches, production bottlenecks and potential safety issues, says the company. New Open Platform Communication (OPC) browsing makes it easier to create watch lists and custom alerts from any OPC Classic data source, including from historians such as the OSIsoft PI System, third-party control systems and PLCs. — *Emerson, St. Louis, Mo.*
www.emerson.com

This temperature and process meter has dedicated apps

The new DP400TP High Speed Meter (photo) features a bright OLED display and a multilingual interface. It also comes with the dedicated Direct Link Google Play App that provides seamless wireless Near-Field Communication (NFC) programming from Android devices. The analog input can be configured by parameter for a wide range of temperature sensors and process signals in milliamps and volts. The OLED display supports graphs with programmable sampling times and bar graphs with alarm thresholds. — *Omega Engineering, Norwalk, Conn.*
www.omega.com

Gerald Ondrey

New Products

Vacuum pump product line for hygienic housekeeping

This company offers a new Wash Down range of suction cups and vacuum pumps (photo) that can be exposed to water and humidity and quickly dismounted, while still maintaining a high performance level. The various components of the Wash Down range, the Easy Clean vacuum pump and the associated suction cups, inserts and accessories tolerate splashing water spray and humid environments and can be used near food or pharmaceutical products. They are designed to favor smooth surfaces and retention-free areas in order to prevent any risk of contamination. As they are made of plastic and stainless-steel materials, the pump components contribute to preserving product hygiene. The nozzle profile of the mixer of the Easy Clean pump operates at a pressure of 4 bars, thus optimizing performance and increasing the efficiency of the suction flowrate. Its compact and lightweight design allows the pump to be installed as close as possible to the suction cups in order to improve production rates. — *Coval Vacuum Technology, Inc., Raleigh, N.C.*

www.coval-inc.com

Bottling machines that count and inspect tablets

At Pack Expo Las Vegas (September 23–25), this company is presenting a monobloc unit (photo) that fills and caps bottles for pills, tablets or capsules. The Compact 12 counter is equipped with special applications to guarantee total product control. One of these is the HarleNIR vision system, which exploits a near infrared (NIR) hyperspectral camera to chemically distinguish the pharmaceutical products by analyzing their active ingredient. The company is said to be the first in the world to implement this technology for packaging blisters. Compact 12 is a monobloc unit that integrates a variety of operations on just one machine. Depending on the type of production and specific user requirements, the machine can accommodate operator protection or product-protection (laminar flow) systems. The machine is set up to handle all the main types of capping systems (screw-on, press-on or crimped) and offers the widest possible array of applications to guarantee total product control. — *Marchesini Group, West Caldwell, N.J.*

www.marchesini.com

These integrated process thermostats are future-proof

The fully redeveloped Integral product line of process thermostats is used for many applications, such as the temperature control of reactors in the chemical and pharmaceutical industries, temperature tests at test stations in the automotive industry, or space simulations in mechanical and electrical engineering. As a result of further development of the models in the T and XT series, the new generation of Integral process thermostats have a variety of new features, including a brand-new, intuitive control concept using mobile devices (photo), increased pump output and a modular, expandable interface concept. — *Lauda GmbH & Co. KG, Lauda-Königshofen, Germany*

www.lauda.de

A flame-detection system with ultra-high-speed response

This company has introduced a new high-speed deluge module (HSDM) for the Eagle Quantum Premier (EQP) fire- and gas-safety controller (photo). The HSDM expands the capability of the EQP so it can activate ultra-high-speed suppression systems for high-hazard applications. According to the National Fire Protection Association (NFPA) Standard for Water Spray Fixed Systems for Fire Protection (NFPA 15), ultra-high-speed detection and releasing systems must be capable of response in 100 ms or less from the presentation of the energy source to the flow of water from the deluge nozzle. The EQP safety system is FM Approved with the HSDM, making it the industry's only listed flame-detection and releasing system capable of ultra-high-speed response, says the manufacturer. — *Det-Tronics Corp., Minneapolis, Minn.*

www.det-tronics.com ■

Gerald Ondrey and Mary Page Bailey

Coval Vacuum Technology

Marchesini Group

Lauda

Det-Tronics

Solids Handling: Friction in Bins and Hoppers

Department Editor: Scott Jenkins

To avoid problems with solids flow in bins and hoppers, the friction between the equipment walls and the flowing solids is an important factor to understand. Provided here is a review of flow patterns in bins and hoppers, and practical design considerations for overcoming challenges related to wall friction.

In the past, bins and hoppers were typically designed primarily from an architectural or fabrication standpoint (for instance, hopper walls were sloped 30 deg from vertical to reduce the waste of wall materials, or 45 deg to minimize headroom requirements and simplify design calculations). However, experience has shown that designing equipment without regard to the actual bulk materials being handled often leads to flow problems, such as arching, ratholing, erratic flow and even no flow. By measuring the flow properties of a bulk solid, including wall friction, the flow behavior of the material can be predicted, and more reliable hoppers and bins can then be designed.

Flow patterns

Two types of bin flow patterns are possible when solid material is discharged from a hopper, bin or silo (Figure). A mass-flow bin has a relatively long, tapered discharge section. In mass flow, all of the material is in motion during discharge, so no stagnant regions form. Conversely, a funnel-flow bin has a relatively short converging section. While storage capacity for a given height is greater in a funnel-flow bin, this geometry allows material in the center to move while material at the walls is stationary. The resultant stagnant regions may interrupt flow.

Frictional properties

Both internal and external friction values are important when characterizing the flow properties of a bulk solid. Internal friction is caused by solid particles flowing against each other, and can be determined using a direct shear tester. External friction is expressed as the wall-friction angle or coefficient of sliding friction. The lower the coefficient of sliding friction, the less steep the hopper walls need to be to achieve mass flow.

Wall-friction test

The test method for wall friction measures interfacial friction between the powder sample and hopper wall material at increasing consolidation stresses. The test is performed using an instrument that involves placing a sample of powder inside a retaining ring on a flat coupon of wall material. Various normal loads are then applied to the powder, and the powder inside the ring is forced to slide along the stationary wall material. The resulting shear stress is measured as a function of the applied normal stress.

The materials of construction used to simulate the surface are based on actual hopper design — instrument vendors provide a range of different grades of steel and plastic routinely used in hopper construction.

The coefficient of sliding friction is the ratio of the shear force required to cause sliding, to the load applied perpendicular to the plate surface. The arctangent of this value is the wall-friction angle.

Wall-friction angles above 30 deg are considered high, and may lead to flow difficulty in powders. Wall-friction results can help determine the recommended hopper angle to ensure mass flow.

Factors affecting friction

The following variables can affect the internal and external friction values of a bulk solid and are similar to those affecting cohesiveness:

Pressure. Typically, as consolidation pressure increases, the effective angle of internal friction decreases. Similarly, the coefficient of sliding friction often decreases as pressure acting normal to the plate increases. However, the internal angle of friction is an intrinsic characteristic of the material, which may increase, decrease, or remain the same as pressure acting on the material increases.

Moisture content. As moisture increases, many bulk solids become more frictional.

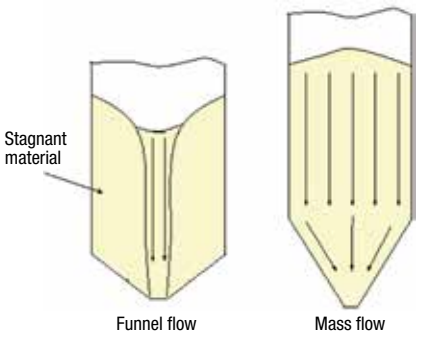


FIGURE. Two types of flow patterns can occur when a bulk solid is discharged from a hopper, bin or silo: A typical funnel flow pattern is shown on the left, and a mass flow pattern is shown on the right

Particle size and shape. Typically, fine materials are somewhat more frictional than coarse materials, so their flow is often more troublesome. Particle shape plays a role also, in that angular particles tend to interlock with each other and also dig into a wall surface, thereby creating more friction.

Design considerations

In cases where powder frictional properties dictate hopper designs that are impractical, alternative options for finding solutions to flow problems could include changes in hopper wall material or an increase in cleaning frequency for the hopper surface. Another approach for improving flowability is to incorporate additives into the powder formulation. Similarly, mechanical-assist devices, such as vibration and aeration, are other possible considerations. Trade-offs must be evaluated between the cost of these interventions versus the consequences of the lost processing time due to flow stoppages related to equipment downtime or poor product that requires rework. ■

Editor's note: The information found in this column was obtained from the following articles:

1. McGregor, R.G., Preventing Flow Stoppages in Powder-Handling Processes, *Chem. Eng.*, April 2018, pp. 48–52.
2. Carson, J., Pittenger, B. and Marinelli, J., Characterize Bulk Solids to Ensure Smooth Flow, *Chem. Eng.*, April 2016, pp. 50–59.
3. Mehos, G. and Morgan, D., Hopper Design Principles, *Chem. Eng.*, January 2016, pp. 58–63.

Ethanolamines from Ethylene Oxide and Ammonia

By Intratec Solutions

Ethanolamines are a family of compounds that are used as feedstocks for emulsifiers, detergents, corrosion inhibitors and chemical intermediates, as well as used for scrubbing carbon dioxide from exhaust gas. The family includes monoethanolamine (MEA), diethanolamine (DEA) and triethanolamine (TEA). As the names suggest, they can be thought as derivatives of ammonia in which the radical $\bullet CH_2–CH_2–OH$ replaces one, two or three, respectively, of the hydrogen atoms in the base ammonia molecule.

Ethanolamines combine interesting chemical properties exhibited by both alcohols and amines. Under acidic conditions, they may either form acids, due to the presence of a basic amine group, or esters, because of the hydroxyl group. MEA and DEA always yield salts if they are in the presence of organic acids.

The process

The following paragraphs describe a process for ethanolamines production from ethylene oxide and ammonia. The process comprises three major sections: (1) reaction, (2) ammonia recovery, and (3) purification (Figure 1).

Reaction. Ammonia is mixed with water to form an aqueous ammonia solution (45–55 wt.% ammonia). Ammonia is supplied in excess to the reactor, so ethylene oxide is fully consumed in the reaction. Water also plays an important role in accelerating the reaction. The reactions achieve yields in the range of 98–99%. The balance is lost in minor side reactions that generate some heavy byproducts, which need to be separated in the purification section. The final product composition depends exclusively on the molar excess of ammonia fed to the reactor. The reactor output comprises MEA, DEA and TEA, as well as unreacted ammonia dissolved in water and the heavy byproducts.

Ammonia recovery. The reaction product is fed to an ammonia stripping column for separating the excess ammonia present in the mixture. Ammonia and water vapors are recycled to the reaction, while the liquid bottom product is routed to a two-stage evaporator and then to a dehydration column, where residual ammonia and water are separated from ethanolamines and also recycled to the reaction area. Ethanolamines are withdrawn as the bottom product of the dehydration column and transferred to the purification section.

Purification. The ammonia-free ethanolamines are further separated in three purification columns. Small amounts of MEA and DEA may also be recycled to the reactor to balance the desired output of each ethanolamine — MEA : DEA : TEA ratios of 1/3 : 1/3 : 1/3. A small stream of heavy byproduct waste is separated in the TEA purification step.

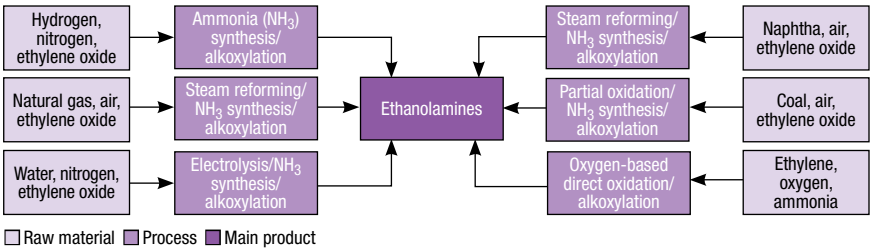


FIGURE 2. Several pathways exist for manufacturing ethanolamines, as shown here

Production pathways

Ethanolamines production is almost exclusively based on the reaction of ammonia with ethylene oxide, in such a way that different ethanolamines manufacturing routes are related to different sources of these raw materials. Pathways for ethanolamines production are presented in Figure 2.

Economic performance

The total operating cost (raw materials, utilities, fixed costs and depreciation costs) estimated to produce ethanolamines was about $1,000 per ton of ethanolamines (MEA : DEA : TEA, in a ratio of 1/3 : 1/3 : 1/3) in the third quarter of 2015. The analysis was based on a plant constructed in the U.S., with the capacity to produce 120,000 metric ton per year of ethanolamines.

This column is based on "Ethanolamines from Ethylene Oxide and Ammonia – Cost Analysis," a report published by Intratec. It can be found at the following URL: www.intratec.us/analysis/monoethanolamine-production-cost. ■

Edited by Scott Jenkins

Editor's note: The content for this column is supplied by Intratec Solutions LLC (Houston; www.intratec.us) and edited by *Chemical Engineering*. The analyses and models presented are prepared on the basis of publicly available and non-confidential information. The content represents the opinions of Intratec only. More information about the methodology for preparing analysis can be found, along with terms of use, at www.intratec.us/che.

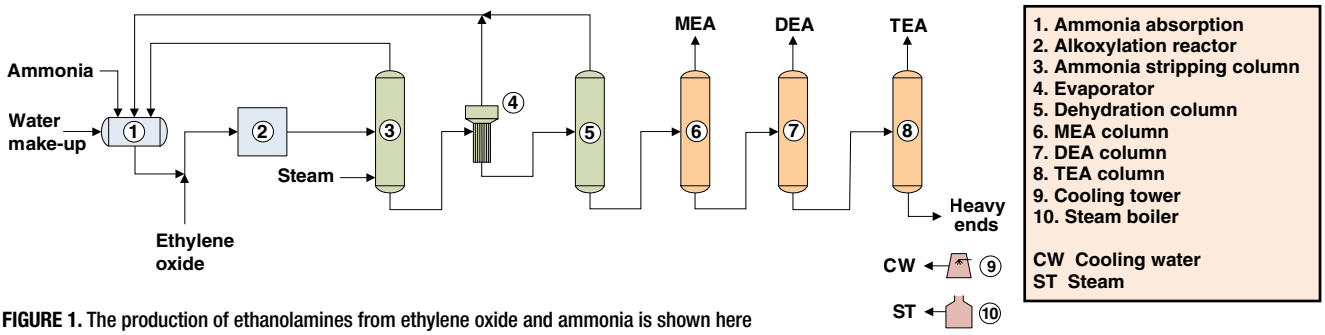


FIGURE 1. The production of ethanolamines from ethylene oxide and ammonia is shown here

Monitoring of Water and Steam Chemistry for Steam Generators

Online monitoring of steam and water chemistry in a steam system is important for safe and reliable operation of steam generators

Brad Buecker
ChemTreat, Inc.

IN BRIEF

High-pressure, high-temperature steam is a critical commodity at power plants and at many chemical process industries (CPI) facilities. Examples abound in heavy industry, where co-generation facilities are common. In these plants, a portion of the steam generated is utilized to drive power-generating turbines, while the remainder is used for other turbine applications or for process heating needs. For instance, in the steel-manufacturing industry, steam-driven turbines serve as the prime mover for the air feed to blast furnaces.

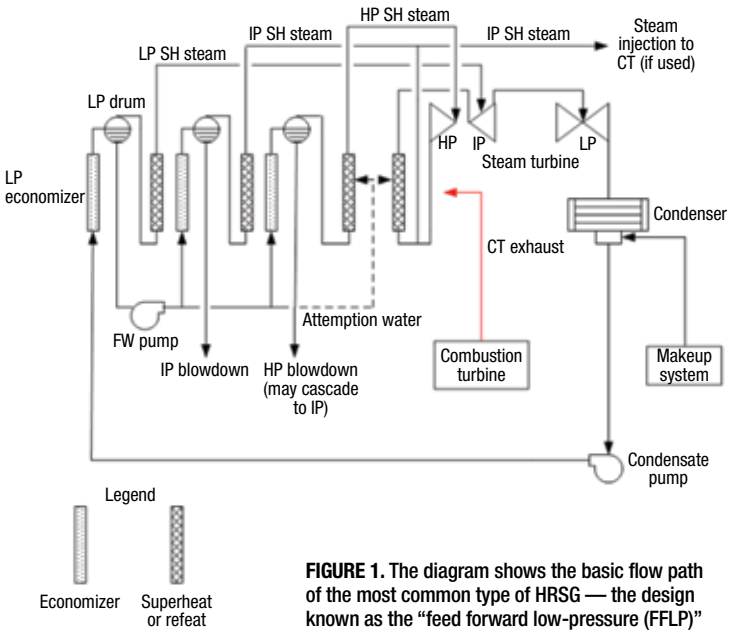


FIGURE 1. The diagram shows the basic flow path of the most common type of HRSG — the design known as the "feed forward low-pressure (FFLP)"

In facilities where steam is generated, it is not uncommon for the control and monitoring of water and steam chemistry to be neglected because intense attention is focused on process operations. Only when a failure occurs is action taken in the area of water/steam chemistry.

In decades past, when conventional coal-fired power generation was the norm, numerous lessons were learned that emphasized the criticality of water- and steam-chemistry monitoring. Many of these lessons were quite dramatic, and, when ignored, underlined the possibility of not only lost production and equipment repair at the facility, but sometimes injuries and fatalities. To avoid such negative occurances, continuous online chemistry monitoring became commonplace at most plants. Now, for both power and industrial-plant steam production, heat recovery steam generators (HRSGs) are a common choice. Unfortunately, a large number of these plants are minimally staffed, often with few, if any, employees that have a strong background in water and steam chemistry. Often, lessons of the past are not considered, leading to a twist on the old saying, "Those who do not understand history are condemned to repeat it." This article reviews the importance of water and steam chemistry for reliable and safe operation in industrial steam systems, and outlines recommended water-monitoring parameters.

FIGURE 2. Tube-wall thinning is caused by single-phase flow-accelerated corrosion

FIGURE 3. The photos show two examples of catastrophic failures induced by flow-accelerated corrosion (source: Ref. 2)

HRSG design: a brief review

High-purity water requirements and water/steam chemistry control and monitoring for HRSGs are similar to those for older, conventional steam generators. However, as compared to coal-fired units, there are some obvious major differences in HRSG design and operation, the most important of which include the following:

- The various waterwall tube and superheat/reheat panels (also known as harps) are aligned in sections along the fluegas path. The waterwall tubes in a coal unit basically form the walls (hence the name waterwall) of a box that surrounds the combustion chamber
- Essentially no ash-fouling potential exists unless the combustion turbine is fired with oil, which is not common
- HRSGs are typically of multi-pressure design, with the most popular having three steam-generating networks (that is, evaporators)

The common term for the boilers in an HRSG is "evaporator," which will appear throughout the remainder of this article.

Sampling points and monitoring

Within a steam-generating network, the samples that are of primary importance for online monitoring of the water/steam chemistry include the following:

- Makeup treatment system
- Condensate pump discharge
- Condensate return (when applicable)
- Feedwater or economizer inlet
- Boiler water
- Saturated steam
- Main and reheat steam

Makeup treatment system. No system is completely closed, and even in the tightest steam generators, a small amount of process water/steam continually escapes. These losses must be made up with high-purity water. The makeup water volume can be quite large if condensate from steam utilized for process heating is not returned to the unit(s). The most common core process is reverse osmosis (RO), followed by either mixed-bed ion exchange (MBIX) or electrodeionization (EDI) to "polish" the RO effluent, especially for high-pressure steam generators. RO units typically include a number of instruments to monitor system performance, including pressure, temperature, flow and specific conductivity. This section focuses upon the recommended analyses of the final effluent from either the MBIX or EDI polisher.

In this and the following sections, the normal upper limit, or a range, for each parameter is included.

- Specific conductivity: ≤0.1 µS/cm
- Silica content: ≤10 parts per billion (ppb)
- Sodium concentration: ≤2 ppb

These measurements ensure that high-purity water is being distributed to the steam generators. A rise in any of the values indicates that either the MBIX resin has reached exhaustion or that a problem has occurred in the EDI unit. Prompt corrective action is necessary in this case.

Condensate pump discharge (CPD). In stand-alone steam-generation power units, the primary location for potential

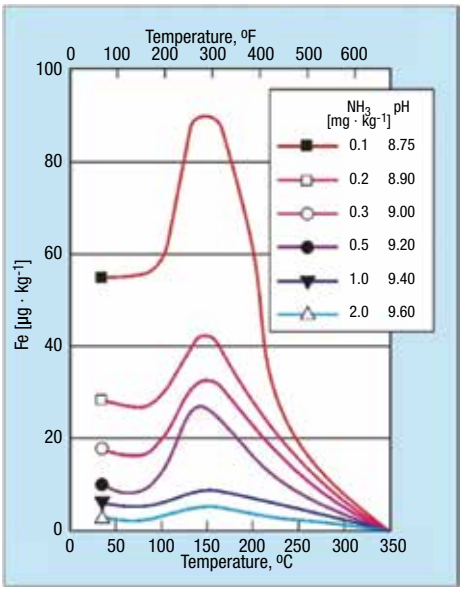


FIGURE 4. The graph shows carbon-steel matrix dissolution as a function of pH and temperature (source: Ref. 2)

contaminant ingress is the condenser, and particularly water-cooled condensers where a tube leak(s) allows cooling water to infiltrate the high-purity condensate. A tube leak will introduce a variety of impurities, including the hardness

FIGURE 5. The photo shows the red coloration of a properly applied AVT(O) program (photo courtesy of Dan Dixon, Lincoln Electric System)

ions (Mg^{2+} and Ca^{2+}), chloride and sulfate, and silica, which when subjected to the harsh environment in the steam generator, can cause serious problems. This will be examined in a later section. A condensate polisher will provide a buffer against contaminant ingress, but polishers are often not considered for drum units, in large measure to reduce project capital cost.

Recommended continuous CPD analyses results are as follows:

• Cation conductivity (CACE):

FIGURE 6. This instrument is a iron digestion unit and spectrophotometer (photo courtesy of Hach)

≤0.2 µS/cm

- Specific conductivity: Consistent with pH
- Sodium concentration: ≤2 ppb
- Dissolved oxygen: ≤20 ppb
- pH: 9.6 to 10.0 (This is the pH range for the HRSG design in Figure 1. The range may be a bit lower for other HRSG designs.)

Sodium monitoring is very effective for detecting condenser tube leaks or perhaps issues related to contaminated condensate return from heating processes. With a tight condenser, sodium ion levels in the condensate are normally very low (<2 ppb), and in many cases, less than 1 ppb. A rise in sodium provides the earliest indication of a condenser tube leak.

Cation conductivity is now often referred to as "conductivity after cation exchange (CACE)" to represent the fact that the sample is routed through a cation exchange column to replace all cations (for example, ammonium, sodium, calcium, and so on) with hydrogen ions. This creates a very dilute acid solution of primarily trace amounts of chloride and sulfate ions, whose conductivity is then measured. As with sodium, a rise in CACE indicates impurity in-leakage, although this measurement is also influenced by carbon dioxide ingression, say from increased air in-leakage at the condenser. Thus, becoming increasingly popular is degasified CACE, which utilizes either a re-boiler or nitrogen sparging compartment to remove CO_2. A low CACE value is a requirement for proper control of all-volatile oxidizing treatment [AVT(O)] chemistry (an offshoot of oxygenated treatment), which is recommended for condensate/feedwater treatment to minimize flow-accelerated corrosion (FAC), and whose details are outlined shortly.

Dissolved oxygen analyses are important for monitoring condenser air in-leakage. A sudden increase in dissolved oxygen may indicate a mechanical failure at or near the condenser, which allows excess air to enter the system. However, with modern AVT(O) chemistry, some dissolved oxygen is required for the chemistry to be effective.

With regard to specific conductivity and pH, ammonia (or sometimes an amine or ammonia/amine blend) is the pH-conditioning agent for condensate/feedwater. However, direct pH measurement of high-purity water can be tricky, and algorithms have been developed to calculate pH based on conductivity measurements to provide more accurate results. Specific conductivity (S.C.) in high-purity water is directly correlated to the ammonia concentration, and thus S.C. measurements offer better control of ammonia feed than pH.

A parameter not typically monitored continuously, but which can be of major importance, is total organic carbon (TOC), as discussed in the next section. For utility steam generators, the normal TOC limit in this sample is 100 ppb.

Condensate return. Steam recovered as condensate from process heat exchangers represents a potentially large source of impurities, which, depending upon the processes and products of the facility, can be inorganic or organic in nature, or may be of particulate form, such as iron oxides. Contaminant ingress from condensate return can be very problematic. For example, the author once visited an organic chemical production plant where substantial organic transport in the condensate return caused drum foaming and subsequent reoccurring failures of the superheat sections of four, 550-psig steam boilers. Tests by the company's water-treatment vendor at the time indicated TOC excursions above 100 parts per million (ppm). The recommended TOC limit for boilers of this pressure is 0.5 ppm. The plant had no condensate polisher on the return line, and no one on staff who understood this chemistry.

For high-pressure steam generators, the condensate return system should have water purity equivalent to the parameters outlined above for the CPD.

Low-pressure (LP) economizer inlet/boiler feed pump discharge. The dominant issue with regard to chemistry control in the HRSG feedwater system (and LP evaporator, as will be discussed) is the minimization of flow-accelerated corrosion (FAC). When the author began his utility career in 1981, conventional wisdom said that any dissolved oxygen that entered the condensate/feedwater system of utility boilers was harmful. At that time, over 50% of the electric power produced in the U.S. came from coal. Coal units typically have complex condensate/feedwater networks with numerous feedwater heaters. A common material for feedwater heater tubes was some type of copper alloy, usually either Admiralty brass or 90%/10% copper-nickel. The prevalent thinking was that any trace of dissolved oxygen (DO) would cause corrosion, and indeed DO can be very corrosive to copper, and to carbon steel in uncontrolled conditions. Therefore, virtually all feedwater systems for high-pressure steam generators were equipped with a deaerator for dissolved gas removal. A properly operating deaerator can lower DO concentrations to 7 ppb.

However, even this residual DO concentration was still considered harmful, so chemical deaeration was also employed at most plants. The chemical of choice for many years was hydrazine (N_2H_4), a reducing agent (also known as an oxygen scavenger), which reacts with oxygen as follows:

$$N_2H_4 + O_2 \;\; —> \;\; 2H_2O + N_2 \text{ (gas)}$$

Hydrazine proved advantageous because it does not add any dissolved solids to the feedwater, it reacts with oxygen in a one-to-one weight ratio, and it is supplied in liquid form at 35% concentration. The primary benefit of hydrazine is that it will passivate oxidized areas of piping and tube materials.

Hydrazine residuals of 20 to perhaps 100 ppb were common. Reducing agent treatment was coupled with feed of ammonia or an amine to maintain feedwater pH within a mildly alkaline range, 8.8 to 9.1 for mixed-metallurgy feedwater systems and a bit higher for all-ferrous (carbon-steel- and stainless-steel-only) systems.

$$NH_3 + H_2O \;—> NH_4^+ + OH^-$$

The use of ammonia (or a neutralizing amine) combined with a reducing agent/oxygen scavenger is the basis of the program known as all-volatile treatment reducing [AVT(R)].

Due to the suspected carcinogenic nature of hydrazine, alternative reducing agents, such as carbohydrazide, methyl ethyl ketoxime, and others, gained popularity. All still had the same purpose — to establish a reducing environment in the feedwater circuit, thus inhibiting oxidation of metal. AVT(R) became a standard in the industry.

"This changed in 1986. On December 9 of that year, an elbow in the condensate system ruptured at the Surry Nuclear Power Station [near Rushmere, Va.]. The failure caused four fatalities and tens of millions of dollars in repair costs and lost revenues" [*1*]. Researchers learned from this accident and others that the reducing environment produced by oxygen scavenger feed results in single-phase flow-accelerated corrosion (FAC). The attack occurs at flow disturbances, such as at elbows in feedwater piping and economizers, feedwater heater drains, locations downstream of valves and reducing fittings, attemperator piping, and, most notably for the combined-cycle industry, in low-pressure economizers and evaporators, and to a lesser (but still important) extent, in intermediate-pressure circuits.

The effect of single-phase FAC is shown in Figure 2. Wall thinning occurs gradually until the remaining material at the affected location can no longer withstand the process pressure, whereupon catastrophic failure occurs (Figure 3).

Two additional factors, pH and temperature, also strongly influence single-phase FAC (Figure 4). As this figure illustrates, corrosion reaches a maximum at 300°F. Thus, feedwater systems, attemperator lines, HRSG LP economizers and evaporators, and to some extent HRSG intermediate pressure (IP) circuits are par-

FIGURE 7. The photo shows a pipe with hydrogen damage. Notice the thick-lipped failure, showing little metal loss

ticularly susceptible locations. Also note the substantial influence of pH on the corrosion characteristics.

An important point highlighted by the graph (and which is a key point of later discussion), is that with proper chemistry, feedwater iron concentrations can be maintained at levels below 2 ppb. Higher concentrations indicate that FAC is in progress somewhere in the system. HRSGs, by their very nature, typically have many short-radius economizer and evaporator elbows, and thus offer many locations for single-phase FAC.

Solutions to single-phase FAC

Nearly a half century ago, researchers and chemists in Germany and Russia began using a program known as oxygenated treatment (OT) to minimize carbon-steel corrosion and iron dissolution in supercritical steam generators. The key component of the program was, and still is, deliberate injection of pure oxygen into the condensate/feedwater network to establish oxygen residuals of up to 300 ppb. What the chemists discovered is that in very pure feedwater (cation conductivity ≤ 0.15 µS), the oxygen will intersperse and overlay magnetite to generate a tenacious and very insoluble film of ferric oxide hydrate (FeOOH). OT typically lowered feedwater iron concentrations to 1 ppb or less, and greatly minimized single-phase FAC. Now, OT is the preferred feedwater treatment for most once-through utility steam generators around the world, unless the feedwater heaters have copper alloy tubes.

Although OT has been successfully applied to drum boilers, the Electric Power Research Institute (EPRI) developed what is known as the all-volatile treatment oxidizing [AVT(O)] program, which is the most common treatment for condensate/feedwater in drum units. AVT(O) relies on the oxygen that enters condensate via condenser air in-leakage, although supplementary oxygen feed may be necessary. When researchers developed AVT(O), they took into account the pH effect on carbon-steel dissolution. Depending upon the HRSG design, the recommended feedwater pH may range from 9.2 to 10.0. Other AVT(O) guidelines are as follows:

- Feedwater DO: 5–10 ppb
- Feedwater cation conductivity limit: ≤ 0.2 µS/cm.

High-purity water is a requirement, because otherwise, substantial oxygen corrosion would result. When properly applied, the initial gray-black magnetite (Fe_3O_4) layer becomes interspersed and overlayed with more protective FeOOH, which produces the "rugged red" color shown in Figure 5.

A critical idea that combined-cycle owners, operators and technical personnel must be aware of is that very rarely, if ever, do the condensate/feedwater systems of HRSGs have any copper alloys within the network. (Copper-alloy condenser tubes are a non-issue with regard to this discussion.) Therefore, no reason exists to employ AVT(R) chemistry; rather AVT(O) should be the choice.

The following parameters are recommended for feedwater chemistry to high-pressure steam generators:

- CACE: ≤0.2 µS/cm
- S.C.: Consistent with pH
- Sodium: ≤2 ppb
- Dissolved oxygen: 5–10 ppb
- pH: 9.6 to 10.0 (This is the pH range for the HRSG design shown in Figure

FIGURE 8. Chloride/sulfate analyzer separates ions in the sample via capillary electrophoresis

1. The range may be a bit lower for other HRSG designs.)

- Iron: ≤2 ppb

The discussion for CACE, S.C., pH, and sodium mirrors that for the condensate pump discharge. These measurements, along with dissolved oxygen, are critical for proper AVT(O) chemistry.

monitoring

- Corrosion product sampling
- Grab sample analysis

With regard to the latter, improved grab sampling techniques are available, in which, with proper sample treatment, iron measurements down to 1 ppb are possible. This method can provide near-realtime data for corrosion rates, although on a "snapshot" basis (Figure 6).

Evaporator water

Evaporator water sampling is critical for two primary reasons. First, poor chemistry control or poor monitoring (or both) can allow unacceptable carryover of excess impurities to the steam. The second reason is that the highest heat fluxes occur within the evaporators (as is the same with conventional units) and particularly the HP evaporator of HRSGs. Thus, the effects of impurity ingress or poor chemistry are magnified by the high temperatures and pressures in these circuits. Consider the classic, longstanding issue of hydrogen damage, which has plagued high-pressure units for decades.

In this mechanism, the most serious corrosive agent (chloride) that enters during a cooling leak can concentrate under waterwall tube deposits and generate acid. The following equation outlines a common mechanism for this process:

$MgCl_2 + 2H_2O + heat \rightarrow Mg(OH)_2 (solid) + 2HCl$

Acid generation is problematic in its own right, but the very small hydrogen atoms will penetrate the steel matrix and then react with carbon in the steel.

$4H + C \rightarrow CH_4$

Formation of voluminous methane molecules induces cracking, which can then induce failures with very little metal loss (Figure 7).

The author once observed the after-effects of severe hydrogen damage on a 1,250 psig boiler, which required complete replacement of the waterwall tubes. Hydrogen damage remains one of the leading corrosion mechanisms in modern steam generators, and is why, as the guidelines below indicate, immediate unit shutdown is required if the boiler water pH drops below 8.0.

Recommended boiler water analyses results include:

- pH (<8.0, immediate boiler shutdown)
- CACE
- Specific conductivity
- Chloride
- Silica
- Phosphate (for those units on phosphate treatment)
- Iron: <5 ppb

The reader will notice no direct limits for most parameters, with the exception of a "drop-dead" lower limit for pH. This is due to the fact that the limits are variable based on boiler pressure. EPRI has published detailed charts for these parameters, but they are only directly available to EPRI members. Other guidelines are available from the International Association of the Properties of Water and Steam (IAPWS; www.iapws.org) at no charge.

Also notice the limit for iron. The LP circuits and some intermediate-pressure (IP) locations in an HRSG can suffer from a phenomenon known as two-phase FAC. Space limitations prevent a discussion of this mechanism here, but iron monitoring is important to ensure that proper chemistry is being maintained in these circuits.

Comment is necessary regarding phosphate. For decades, tri-sodium phosphate (Na_3PO_4) has been a core boiler-water-treatment chemical in many drum units. However, control of the phosphate concentration is difficult due to the compound's reverse solubility above 300°F. Some plant personnel, especially in the power industry, have switched to a caustic (NaOH) feed to eliminate phosphate "hideout," but great care is required with these programs to prevent caustic gouging of waterwall tubes. Similar in some respects to the acid corrosion described earlier, caustic can concentrate under porous deposits (usually iron oxide corrosion products that carry over from feedwater or condensate return systems) to directly attack the metal. Inclusion of a condensate polisher in the system design offers the opportunity to eliminate phosphate or caustic from the boiler-water-treatment program.

Steam-purity measurements are important, particularly if the steams drives a turbine or turbines. Contaminant deposition on turbine blades can lead to corrosion and possible blade failure — a potentially catastrophic situation

Steam purity

Steam-purity measurements are very important, and particularly if the steam drives a turbine or turbines. Contaminant deposition on turbine blades can lead to corrosion and possible blade failures, which represent a potentially catastrophic situation with the turbine spinning at several thousand revolutions per minute. Core monitoring parameters include the following:

- CACE: ≤0.2 µS/cm
- Sodium: ≤2 ppb

- Silica: ≤10 ppb

Sodium provides a direct indication of salt or sodium hydroxide carryover with the steam. Salts, and particularly chloride salts, will settle in the last rows of the low-pressure turbine, where they can cause pitting and subsequent stress corrosion cracking (SCC) and corrosion fatigue (CF) of turbine blades and rotors. Sodium hydroxide carryover is a very serious issue, because caustic can quickly induce SCC of turbine components.

CACE provides a surrogate measurement of chloride and sulfate carryover, and has been a long-time guideline for turbine manufacturers. However, the accuracy of CACE is suspect, especially given that the limit for both impurities is 2 ppb, similar to sodium. A new instrument has emerged on the market that allows analyses of these two impurities down to a 0.1 ppb level (Figure 8).

It has long been known that silica in steam will precipitate on turbine blades. While the compound is not corrosive, it can influence turbine aerodynamics and reduce efficiency. Thus, the 10-ppb recommended limit.

Several steam sampling points are available in power generating units. These include saturated, main and reheat steam samples. Main and reheat steam are the most important, as they provide data on impurities directly entering the turbine, which can also come from contaminated steam attemperation water. Measurement of saturated steam is less important, but can be valuable on a periodic basis to check for mechanical carryover issues from steam drums. Failed or damaged steam separators are a common cause of mechanical carryover.

Smart systems

Organizations such as EPRI have been performing much work in the development of "smart systems" that integrate instrument data into outputs that provide information on overall steam-generation chemistry. For example, if an HRSG is equipped with both CPD and feedwater sodium and CACE analyzers, and only one is giving high readings, instrument

error is the likely culprit. However, if all four are out of normal range, contamination from a condenser tube leak or makeup system upset is the likely cause. This can be narrowed further by comparing CPD readings with makeup system effluent values. Numerous other integrated evaluations are possible, and use of a program that examines all data and provides intelligent outputs to plant operators and technical personnel can be extremely valuable in identifying specific upsets before they become major problems. For instance, the makeup water system at a CPI facility may be fine, and all turbine condensers are in good order, but a leak in a process heat exchanger may be fouling the condensate return. With the proper instrumentation in place, a smart system will quickly analyze the issue and alert the plant staff. This article has outlined fundamental guidelines, but each system is different and therefore, consultation with a water treatment expert is recommended to address the details of your system. ■

Edited by Scott Jenkins

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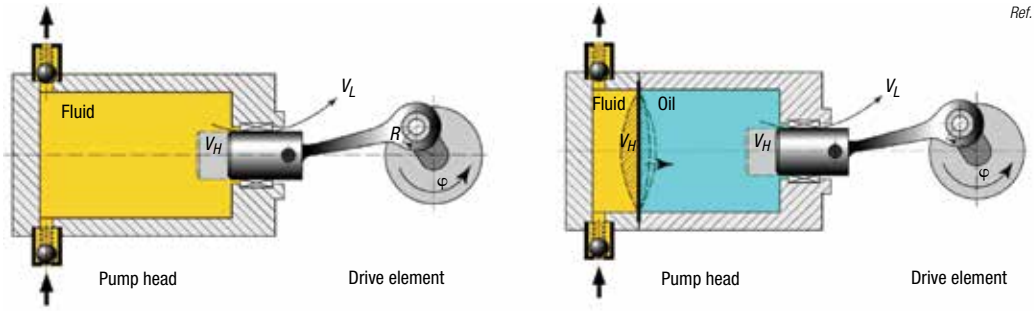
Author

Brad Buecker is the senior technical publicist with ChemTreat, Inc. (5460 Cox Road, Glen Allen, VA 23060; Phone: 1-804-935-2000; Email: bradley.buecker@chemtreat.com). He has 36 years of experience in or affiliated with the power industry, much of it in steam generation chemistry, water treatment, air quality control, and results-engineering positions with City Water, Light & Power (Springfield, Illinois) and Kansas City Power & Light Company's La Cygne, Kansas station. He also spent two years as acting water/wastewater supervisor at a chemical plant. Most recently, he was a technical specialist with Kiewit Engineering Group Inc. Buecker has a bachelor's degree in chemistry from Iowa State University, with additional course work in fluid mechanics, energy and materials balances, and advanced inorganic chemistry. He is a member of the American Chemical Society, American Institute of Chemical Engineers, American Society of Mechanical Engineers, Association of Iron and Steel Technology, Cooling Technology Institute (via corporate membership), National Association of Corrosion Engineers, the Electric Utility Chemistry Workshop planning committee, the Advisory Council for the International Water Conference, the EPRI-sponsored Power Plant & Environmental Chemistry Committee, and the Power-Gen International planning committee. Buecker has authored many articles and three books on power plant and water/steam chemistry topics.

A Primer on Reciprocating Metering Pump Technologies

Understanding what technology is available is a first step towards selecting the right pump for metering applications



Ref. 2

FIGURE 1. These diagrams show the principle designs of a piston pump (left) and a diaphragm pump (right)

Nils Kohlhase
University for Applied Science in Lübeck

IN BRIEF

Reciprocating metering pumps are problem solvers for difficult fluid-handling tasks and applications. Their main function is the metering of a precise fluid volume per stroke in a specified period of time. For this, the accuracy of the metering flow is the critical, value-added element of these pumps. They are used in different industries, such as the chemical, oil-and-gas and pharmaceutical industries for applications with partially specific properties. While operating pressures can range from atmospheric pressure to 3,500 bars, the properties of the fluids can be extreme. Examples are applications with very low or high temperature, very high or low viscosity, thixotropic fluid behavior, shear sensitivity, abrasiveness due to solid contents, toxic or corrosive behavior.

Basic constructions

The pumps consist of two main elements: the drive element and the pump head, as shown in Figure 1. The drive element converts the electrical energy into the reciprocating movement of the plunger while the main task of the pump head is the metering of the fluid. For most of the pumps, the stroke length can be adjusted for different flowrates. Due to this, reciprocating pumps have the following three characteristic properties (Figure 2):

- The flowrate is extraordinarily independent of the discharge pressure, in comparison to other types of pumps
- A digital character of the flowrate over time
- A linear dependence of the metering flow on stroke length and stroke frequency

Drive elements

Many different drive designs are available on the market today. Important requirements for these drive elements are as follows [*1*]:

- Rugged design, capable of sustaining overload
- Adjustable stroke length
- Linearity between stroke adjustment and stroke length
- Harmonic reciprocation motion with continuous plunger viscosity curve over the stroke length
- Constant front dead point, independent of

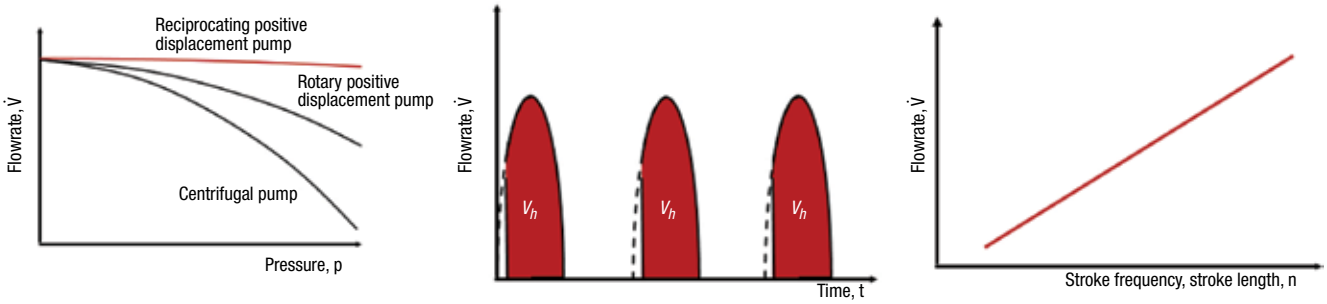


FIGURE 2. These graphs show the main characteristics of reciprocating diaphragm pumps

FIGURE 3. Different concepts for drive elements are presented here

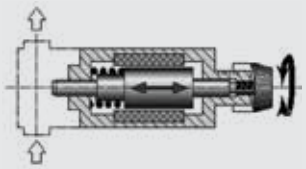
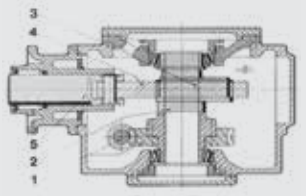
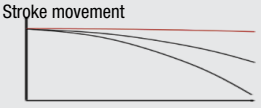
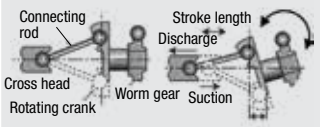
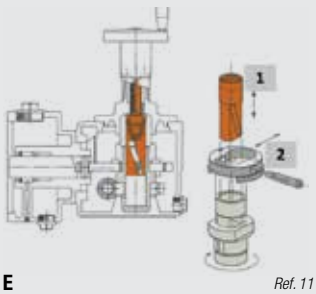
stroke-length setting

The last two requirements are prerequisites for an optimum pump-head operation. A discontinuous viscosity curve can lead to hydraulic pressure shocks. And a constant front dead point is important to reduce the pump head efficiency and metering accuracy at partial stroke length. Figure 3 shows five different principle designs and their properties.

The cam drive concept (Figure 3C) is an interesting solution for small- and mid-size discharge powers. It has a constant front dead point, which is the precondition for small pump-head dead spaces, and linearity between stroke adjustment and stroke length. This guarantees a very precise adjustment. The main disadvantage of the cam drive concept is the shock-like kinematics in partial stroke range. Depending on the adjusted stroke length, the adjustment screw blocks the movement of the plunger abruptly in the suction stroke. This leads to mechanical and hydraulic pressure shocks. With small pumps, these shocks can be acceptable, but for larger discharge powers, cam drives are not optimal.

A good compromise for mid-size to high-hydraulic power is the crank drive with variable eccentricity principle (Figure 3E). As shown in the right-hand side of Figure 3E, a mechanism converts the axial movement of the wedge (1) into a radial movement of the eccentric disk (2) for the adjustment of the stroke length of the crank. Due to the crank drive, the center point of the movement at partial stroke is constant. Thus, the front dead point varies at partial stroke length. This is the only disadvantage of this drive principle.

DIFFERENT CONCEPTS FOR DRIVE ELEMENTS

Drive	Mechanical stroke adjustment	Example	Properties
Solenoid	Yes	 **A** *Ref. 1*	**Solenoid drive** •Economic solution for small power •Direct conversion into reciprocating movement with integrated stroke adjustment •Linear stroke adjustment •No harmonic reciprocation motion •Constant front dead point
Motor	No	 **B** *Ref. 1*	**Straight crank drive** •Rugged design possible •No stroke adjustment Nearly harmonic oscillating movement
	Yes	Stroke movement  **C**	**Cam drive** •Economic solution for small and mid-sized power •Linear stroke adjustment •At partial stroke length no harmonic reciprocation motion •Constant front dead point
		 **D** *Ref. 11*	**Revolving crank mechanism** •Rugged design possible •Very often no linear stroke adjustment •Nearly harmonic reciprocation motion •Constant front dead point possible
		 **E** *Ref. 11*	**Crank drive with variable eccentricity** •Rugged design possible •Linear stroke adjustment •Nearly harmonic reciprocation motion •No constant front dead point

Ref. 3

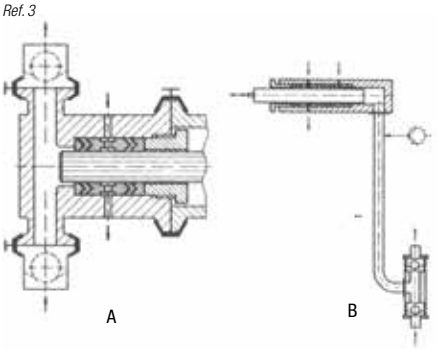


FIGURE 4. Plunger pumps can be equipped with sterile interfaces with flushing provisions (a) and different systems for the flushing of seals (b) to separate particles from seals

Ref. 3

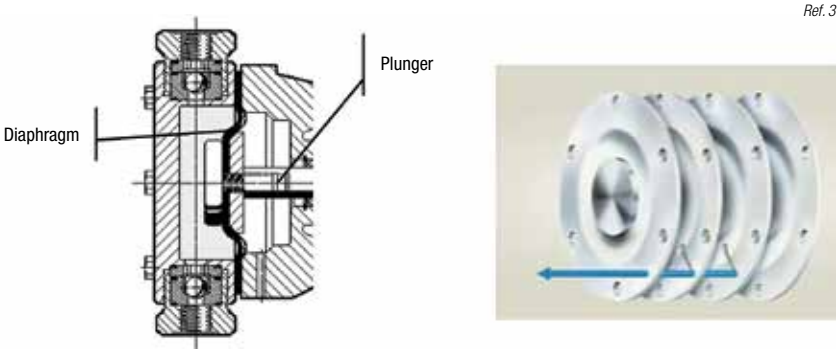


FIGURE 5. In mechanically coupled diaphragm pumps, the diaphragm is directly assembled to the plunger. The diaphragm has to seal and to convey against the operating pressure. Therefore, such pumps are suitable for low-pressure applications and smaller flowrates

In recent years, new drive elements with integrated servo drives have been developed. One supplier, for example, has used the existing mechanics of the drive elements [*12*]. In the automotive industry, servo-driven piston pumps are used to apply adhesive [*14*]. These meters use roller screw drives for the conversion into a reciprocating movement. This is possible because the stroke frequency is very low with one stroke per minute. Both solutions can generate the partial stroke by controlling the movement of the servo drive. They allow individual suction and discharge stroke characteristics for high-viscosity fluids, easy data communication with other systems and easy integration into process control systems. It is to be expected that more drive elements with servo drives will be required in the future.

Pump heads

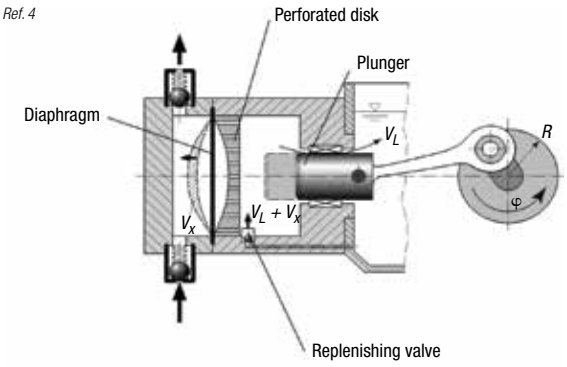
Pump heads can be classified as either plunger- or diaphragm-type pump heads.

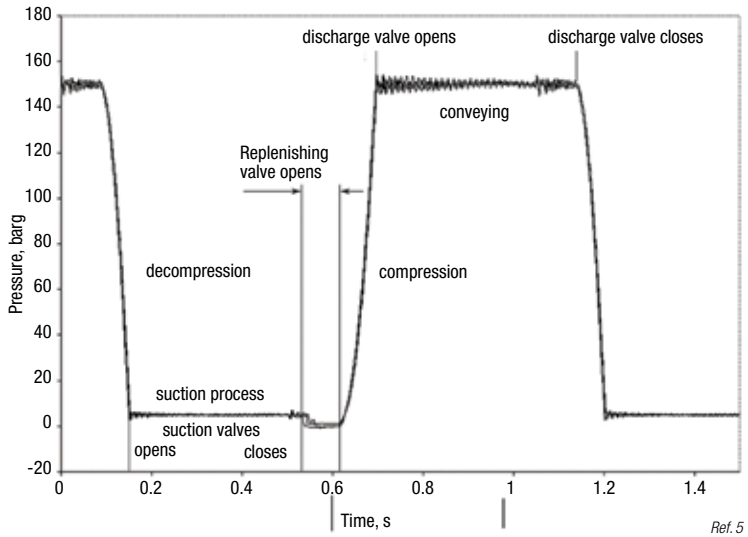
Plunger pump heads. Plunger pump heads are comparable economic solutions for metering applications when leak-free solutions are not required. They are suitable for extreme operating conditions like very high or low temperature or the highest pressures.

The sealing concept is very important for this type of pump head. All efforts to improve the operational response of seals cannot overcome the fact that leakage flows are unavoidable in dynamically operating seals. Often, small flows are even functionally necessary for lubrication. Most of the sealing solutions have been proven for years. Standard sealing solutions are single- or double-tensioned gland packing for pressure up to 500 bars and temperature up to 400°C. For excluding contamination or infection entering from the outside, for example, in the pharmaceutical industry, sterilizing flushing of the seals (with wet steam, for example) creates safely operating sterile interfaces, as shown in Figure 4. Especially for suspensions, the sealant can be protected by forced flushing of a front-side sealing gap into the working chamber. Various configurations have been applied successfully for this purpose [*3*].

Diaphragm pump heads. The main advantage of diaphragm metering pumps against plunger pumps is the hermetically sealed tightness of the pump head. Instead of a dynamic sealant, the pump head is equipped with a diaphragm that serves as a flexible, static seal. Therefore, these pump heads are compatible with difficult-to-handle fluids, such as toxic, flammable and corrosive fluids, as

Ref. 4



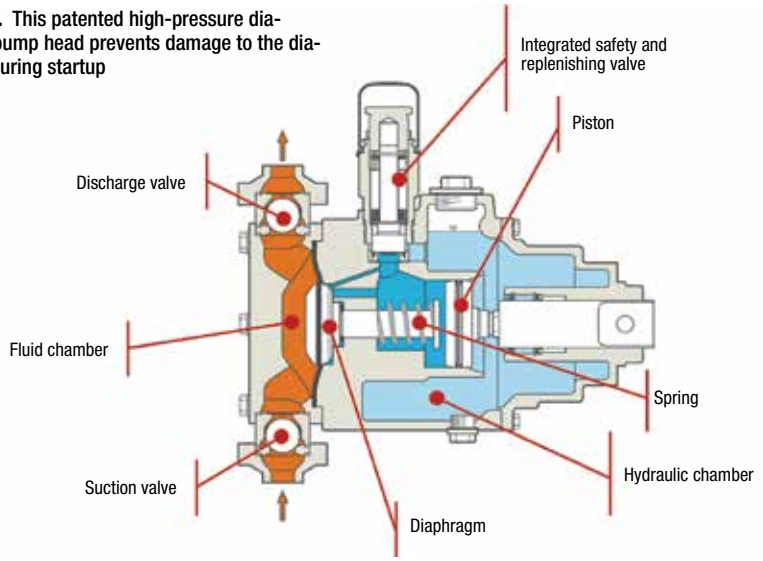


Ref. 5

FIGURE 6. (Above) In a hydraulically coupled diaphragm-pump head, the diaphragm separates the pressure chamber into an operating chamber and a hydraulic chamber

FIGURE 7. (Right) This graph shows the pressure behavior of a diaphragm pump versus time

FIGURE 8. This patented high-pressure diaphragm-pump head prevents damage to the diaphragm during startup



Ref. 13

well as slurries, thixotropic, high-viscous or non-lubricating fluids. In terms of the hydraulic power, it makes sense to distinguish between mechanically and hydraulically coupled diaphragms.

For low-pressure applications and smaller flowrates, pump heads with mechanically coupled diaphragms have found a broad market. At these pumps the diaphragm is directly assembled to the plunger, as shown in Figure 5. The diaphragm has to seal and to convey fluid against the operating pressure. This is the reason for the relatively small allowed operating pressure (up to about 20 bars) compared with hydraulically coupled diaphragm pump heads. In many cases, the pump head is combined with cam drives as drive elements. Qualified designs should have at least the following properties:

- A diaphragm lifetime of at least 5,000 operating hours, depending on the operating pressure and the diaphragm deflection
- Diaphragm material with high diffusion strength and chemical stability. Many suppliers use polytetrafluoroethylene (PTFE) or PTFE-coated rubber for this
- Multi-layer diaphragm with integrated diaphragm-monitoring system to indicate diaphragm failure and guarantee tightness — also after diaphragm rupture

If the diaphragm is hydraulically coupled, an operating pressure of up to 800 bars is possible with a PTFE diaphragm, and up to 1,200 bars is possible with a stainless-steel diaphragm. These pump heads are used in a broad range of 0.1 mL/h to about 60 m^3/h.

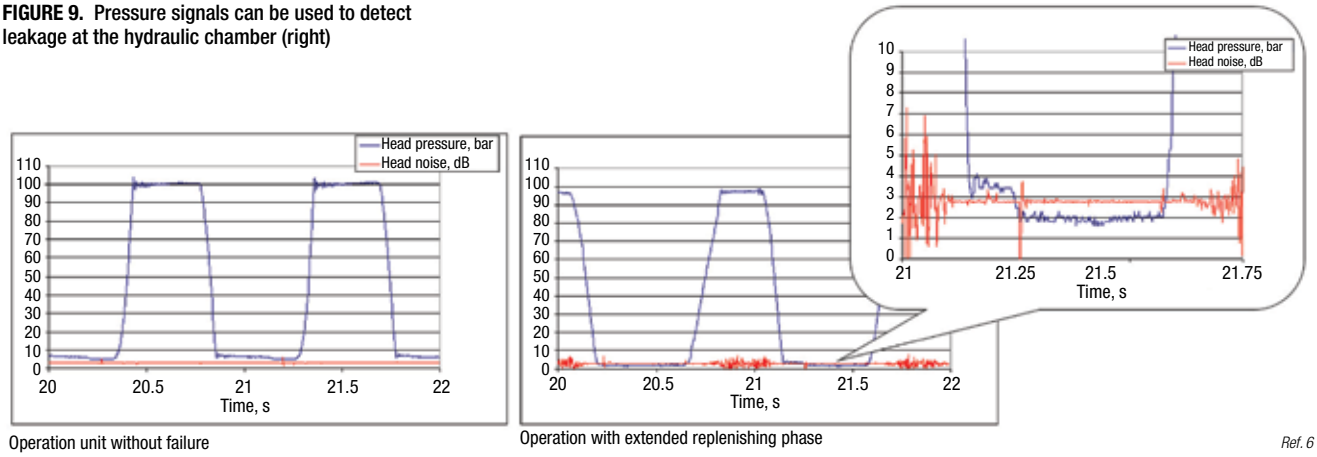
The principle design of a hydraulically coupled diaphragm pump is shown in Figure 6. The diaphragm separates the pressure chamber into an operating chamber and a hydraulic chamber. Therefore, the pressure in both chambers is identical. The diaphragm has the following two functions:

- To transmit the plunger displacement of the hydraulic fluid onto the metering fluid — under normal operating conditions, the pressure on both sides of the diaphragm is nearly identical
- To seal the operating fluid against the environment at the diaphragm clamping area

Due to the oil leakage at the plunger seal, a replenishing valve is needed. It opens when the diaphragm contacts the perforated plate. The hydraulic chamber can also be equipped with a safety valve to prevent overpressure (not shown in Figure 6). Figure 7 shows the operating pressure as a function of time for a diaphragm pump, where one can see the interaction of the valves. In the diagram, the suction and discharge strokes, the opening time of the suction and discharge valves, the compression and decompression phases and the opening time of the replenishing valve are clearly recognizable.

As mentioned before, the diaphragm material is usually PTFE for pressures up to 800 bars and stainless steel for pressures up to 1,200 bars. State-of-the-art for PTFE material is a double-layer diaphragm with integrated monitoring system to indicate diaphragm rupture and

FIGURE 9. Pressure signals can be used to detect leakage at the hydraulic chamber (right)



Ref. 6

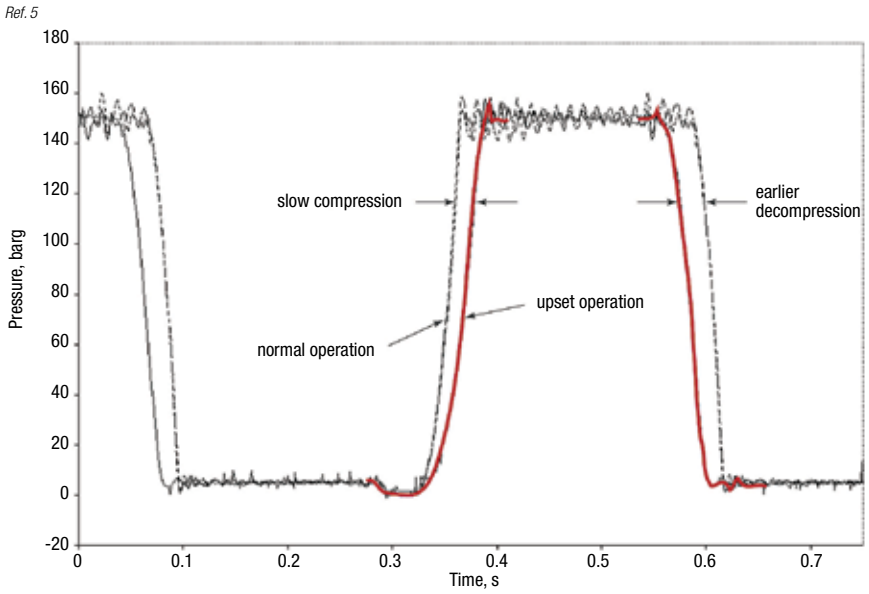


FIGURE 10. This graph shows the change in the pressure signal when the suction valve is defective

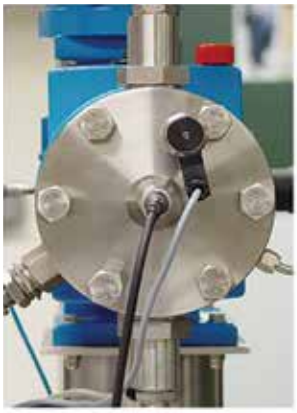
to prevent leakage. The lifetime of a PTFE diaphragm can exceed 10,000 h operating time. Standard material for wetted parts, such as pumps heads and valves, is stainless steel, for example 316Ti (1.4571). For specific process requirements, these parts can be made of special materials, such as stainless steel 316/316L (1.4401/1.4404), Hastelloy or Duplex steel and polyvinyl chloride (PVC).

When the suction line pressure is below ambient pressure during standstill, the start procedure of a metering pump can be critical for the diaphragm. Due to very low leakage at the suction valve and at the piston seal, the diaphragm can move over time to the front dead point. If the piston has remained in the rear position, the diaphragm would be overstretched or damaged at the first stroke after pump start. In order to prevent this, a specific starting procedure is necessary. Pumps have to be started with zero stroke length and slowly increase the stroke length afterwards. Figure 8 shows a modern, patented diaphragm-pump head that prevents this situation from happening. An installed spring tears the diaphragm to the rear position during standstill. Easy and safe starting, even under extreme conditions, is the result. Furthermore, the spring ensures a stable diaphragm displacement and a significantly lower minimum-required suction flange pressure at the pump entry in many applications.

Condition monitoring

The fluid valves and the diaphragm are the major wear parts of the pump head. In order to reduce lifecycle cost and to increase the pump-head reliability, monitoring systems help to recognize developing failures at an early stage for predictive maintenance. While the double-layer PTFE diaphragms are already monitored, the technology to indicate and to predict valve failures is known [*5–7*]. The basis for

A valve failure in a diaphragm pump can be detected by two intependent and redundant signals.



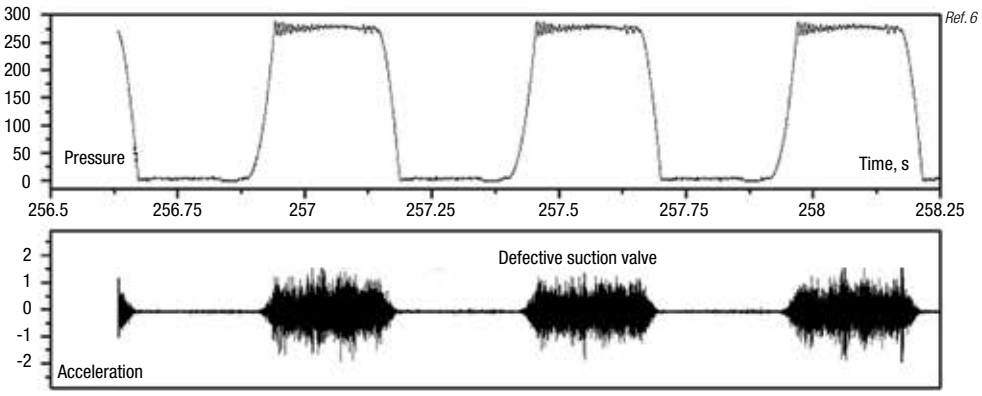


FIGURE 11. Defective suction valves can be detected with acceleration sensors

this monitoring system is a pressure sensor to detect the operating pressure as a function of time, as shown in Figure 7, and an accelerometer for acceleration measurement. The accelerometer can be assembled at the front of the pump head, while the pressure transducer can be installed in the hydraulic chamber. At commissioning, a fingerprint of the signals has to be learned by the system. Figure 9 shows the pressure versus time diagram in normal (left) and faulty operation. The replenishing valve in the hydraulic chamber is open for a longer period of time in case of leakages of the hydraulic chamber (due to defective piston rings or hydraulic valves). If the suction valve is defective, the compression starts later and lasts longer, whereas the decompression takes place earlier. This behavior is shown in Figure 10. The reason for this is fluid that is forced back into the suction line if the suction valve does not close properly although the pump produces the operating pressure required. In case of a defective discharge valve, the compression would be faster and decompression slower. The existing pressure in the discharge line supports the compression and maintains the pressure for a longer time period during the decompression. In addition, the

acceleration signal indicates clearly the defective suction valve, as shown in Figure 11. This shows that a valve failure can be detected by two independent and redundant signals.

Outlook

According to estimates by the German Association of the Chemical-Pharmaceutical Industry (VCI), 9% of the investment costs of a process plant in Germany are accounted for by redundant pump systems [*8*]. At the pump side, the technology for monitoring valves seems to be clarified. But we have a lack of field experience. This could change in the course of the digitalization strategy of the chemical and oil-and-gas industries. Companies, such as BASF, have declared that they want to use data to better forecast maintenance requirements of their plants and reduce unexpected shutdowns [*9*]. And Shell clearly describes the advantages of predictive maintenance: "The objective is an increase in reliability of the overall asset or part of the asset" [*10*]. In connection with the discussion of the internet of things (IoT), it is to be expected that the demand for condition monitoring and predictive maintenance systems will continue to increase for metering pumps as well. And that is a very promising development, because only intensive field experience ensures enough confidence in these systems. ■

Edited by Gerald Ondrey

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CEM

Bionomic Industries

From October 22–24, professionals from all sectors of the chemical process industries (CPI) will meet in New York City for the 2019 Chem Show (www.chemshow.com). With over 275 exhibitors, Chem Show's exhibit hall will feature demonstrations of new process equipment and other innovative technologies. The seminar program offers numerous technical sessions that provide attendees with process insights, ranging from safety best practices to energy efficiency and economic viability. Some of the technical sessions' focus areas include guidance on shutdown events and disaster planning; integrated systems and digitalization; and general CPI best practices, including troubleshooting and management of change. This Show Preview covers a small selection of the process equipment that will be showcased at the 2019 Chem Show.

As part of its seminar program, the Chem Show will host presentations from the 2019 finalists for the Kirkpatrick Chemical Engineering Achievement Award, which is given every two years by *Chemical Engineering* to honor the most noteworthy chemical engineering technologies to reach commercialization. The finalists were selected by a panel of judges consisting of chemical engineering department heads at accredited universities. Each finalist company has been invited to give a presentation outlining its nominated technology during the Chem Show. The 2019 Kirkpatrick finalists are summarized below:

- Braskem is nominated for its development of a process to manufacture renewable ethyl vinyl acetate (EVA)
- Dow Packaging and Specialty Plastics is nominated for the Symbiex adhesive technology for laminated multilayer packaging
- Johnson Matthey is nominated for the Catacel SSR catalyst, which can decrease pressure drop while increasing heat transfer and catalytic activity in steam methane reformers
- LanzaTech is nominated for its gas fermentation technology, which converts carbon-rich gas streams, such as industrial emissions and other waste streams, to products, using proprietary microbes that feed on gases rather than sugars
- Reliance Industries is nominated for the simultaneous production of benzene and gasoline from the C6 heart cut of fluid catalytic cracker (FCC) gasoline using extractive distillation
- TechnipFMC is nominated for the Direct Heating Unit (Flameless Combustion) technology, which adds heat to high-temperature processes in a more controlled and efficient manner than classic combustion

Extremely fast infrared moisture analysis

The Smart Q Quartz halogen moisture analyzer (photo) is said to be the fastest infrared (IR) moisture analyzer currently on the market. High-quality, analytical-grade internal components are housed within an extremely rugged shell, making the Smart Q suitable for both laboratory and manufacturing settings. Smart Q is especially beneficial to users who prefer an IR-only loss-on-drying method, in a wide variety of industries, including pharmaceuticals, plastics, processed foods and many more. Booth 724 — *CEM Corp., Matthews, N.C.*
www.cem.com

Efficient emissions-removal systems for venting operations

ScrubPac VentClean Systems (photo) are compact, complete systems that can provide over 99% removal of storage-tank and rail-car vent emissions caused by breathing and filling operations. The system uses a triple-action scrubbing technology, is available in four model sizes — L, M, H and EH — to handle gas capacities from 0 to 1,500 ft^3/min, and two unique operating configurations that easily adapt to a variety of scrubbing liquid preferences. Booth 316 — *Bionomic Industries, Inc., Mahwah, N.J.*
www.bionomicind.com

Effective screening designs for solid-liquid separations

The Ultra-Vib vibrating screener (photo, p. 51) utilizes a high-frequency, straight motion that facilitates effective liquid-solid separation. The rugged Ultra-Vib uses a pre-tensioned screen cloth mounted on a steel square-tube frame. The screen frame assemblies

are easy to install and remove without the use of any tools. Spring-loaded clamps on the outside box hold the screen in place. This company also offers the MR Gyra-Vib separator, which utilizes a center-mounted motor and unique weight system to control the vibratory screening motion during the screening process. Simplified change of the lead angle of the weights provides for optimal flow patterns in a wide variety of process applications, including sifting, scalping, classifying and dewatering. Booth 329 — *Midwestern Industries, Inc., Massillon, Ohio*
www.midwesternind.com

These rugged flowmeters now offer expanded FM approvals

The In-Flow line of rugged mass flowmeters and controllers (photo) can now be offered with FM approval for Class I, Div. 2 in the North American market. The instruments are available for flow ranges from 0.05 to 1 mL/min up to 200 to 10,000 m^3/h air-equivalent. The In-Flow Series is also available with optional ATEX approval for use in Category 3, Zone 2 hazardous areas and are designed according to IP65 to be dust- and waterproof. Furthermore, this company has also made available a Profinet fieldbus interface on its flowmeters and controllers for gases. Depending on user requirements, In-Flow devices can be equipped with one of the six available fieldbus interface options. Booth 109 — *Bronkhorst USA, Inc., Bethlehem, Pa.*
www.bronkhorstusa.com

A two-stage water filter that saves space

The CSF-ABW automatic filter (photo, p. 52) is a two-stage self-cleaning water filter manufactured in one vessel, used for cleaning debris in various water sources. By combining two filtration concepts into a single device, the CSF-ABW saves time and space for users. The CSF-ABW comprises two stages: a coarse-screen flushing

Midwestern Industries

Bronkhorst USA

Tekleen

Lutz Pumps

Rosedale Products

filter with a 1/8–1/2-in. slotted screen for quick self-cleaning; and a finer filter with screening capabilities down to 75 µm. These new automated filters offer direct filtration of nearly any dirty water source. Booth 605 — *Tekleen Automatic Filters, Inc., Los Angeles, Calif.*
www.tekleen.com

This compact compressed-air motor consumes less air

MDx compressed-air motors (photo) enable users to achieve the same delivery capacity with 20% less connection pressure and 4% less air consumption comparable to other products, according to the manufacturer. The 1,000-W air motor optimizes flow control for high power and efficiency, and an oil-free version is also available. Modular construction means that the motor can be easily installed and retrofitted. ATEX certification is available for challenging environments. Booth 212 — *Lutz Pumps, Inc., Norcross, Ga.*
www.lutzpumpsamerica.com

Five-layer filter bags with a long service life

HL filter bags (photo) have five layers of filter material, each with 4.4 ft^2 of surface area. These bags have a molded-flange or stainless-steel ring to ensure a positive seal with the filter housing. They are constructed with two gradient layers of polypropylene (PP) or polyester felt separated by a transfer/caking filter layer. The initial layer is for pre-filtration and the final layer is a mesh-fiber anti-media-migration layer. The filter bags are said to provide a very long service life. Booth 704 — *Rosedale Products, Inc., Ann Arbor, Mich.*
www.rosedaleproducts.com

Compact analyzers with single- or dual-wavelength options

The Cora 5X00 series of portable benchtop Raman spectrometers (photo, p. 53) can analyze different kinds of samples with a maximum Raman signal and minimum fluorescence. Users may choose between

single- or dual-wavelength instruments. Cora 5X00 equipment can be operated as a standalone instrument using the embedded PC and touchscreen or, alternatively, via an external tablet or PC. The battery option increases mobility and allows use in the warehouse, field or laboratory. Booth 327 —*Anton Paar USA Inc., Ashland, Va.*

Anton Paar USA

www.anton-paar.com

This flow-microscopy system for particle analysis can hold up to 96 samples

FlowCam 8000 is an imaging particle-analysis system that uses flow microscopy to image and analyze subvisible particles with diameters ranging from 1 to 600 µm. The system can simultaneously determine particle shape, type and size distribution of all detectable particles in a solution. Furthermore, this company offers the FlowCam Automated Liquid Handling (ALH) system (photo), which integrates with the FlowCam 8000 for uninterrupted processing of samples. The system allows up to 96 samples to be queued for unattended operation, improved repeatability and increased productivity. Booth 550 — *Fluid Imaging Technologies, Inc., Scarborough, Maine*

Fluid Imaging Technologies

www.fluidimaging.com

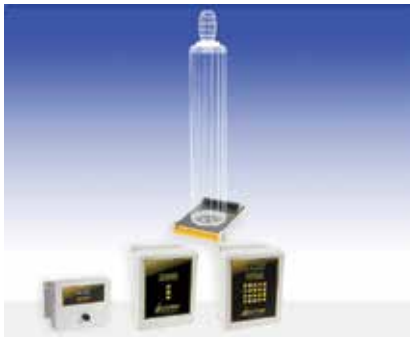
A multifunctional process calibrator and communicator for field use

The MC6 (photo) is a high-accuracy field calibrator and communicator that can calibrate process instruments, such as thermocouples, resistance temperature detectors (RTDs), pressure transmitters, temperature transmitters and multivariable transmitters. It offers calibration capabilities for pressure, temperature and various electrical signals. A multi-bus field communicator is built into the MC6 calibrator. It includes HART, Foundation Fieldbus H1 and Profibus PA communication all in one device. A backlit 5.7-in. color touchscreen can be used with bare fingers, with gloved fingers or with a stylus. An intuitive user interface with multiple languages is also included. Booth 509 — *Beamex, Inc., Marietta, Ga.*

Beamex

www.beamex.com/us

Mary Page Bailey



Scaletron Industries

Dräger

GF Piping Systems

Assmann Corp. of America

The 92nd annual Water Environment Federation Technical Exhibition and Conference (Weftec; www.weftec.org) will be held September 21–25 at the McCormick Place Convention Center in Chicago, Ill. Weftec features an extensive lineup of technical presentations focused on best practices and new technologies in water and wastewater treatment, as well as an exhibition hall that will be open from Sept. 23–25 and will feature more than 1,000 exhibitors who will showcase the latest equipment used in water-treatment processes. The conference program consists of over 140 technical sessions and over 30 workshops, as well as facility tours. The following preview highlights a small sampling of the products and services that will be displayed at Weftec.

Use these scales with corrosive materials

This company offers a wide range of 150-lb cylinder scales (photo) that are used for weighing and monitoring the usage of corrosive chemicals, including liquefied gases, such as chlorine, sulfur dioxide, ammonia, hydrogen chloride and carbon dioxide, which are packaged in cylinders up to 12 in. in diameter. The scales feature a corrosion-resistant construction, and are available with digital and mechanical components. Single- and multiple-cylinder models are available. The scales' low-profile platform design increases safety and ease of cylinder handling. Booth 5248 — *Scaletron Industries Ltd., Plumsteadville, Pa.*
www.scaletronscales.com

Integrated gas detector makes laboratory analysis portable

The X-pid (photo) is an intrinsically safe gas detector that can detect benzene, butadiene and other volatile organic compounds (VOCs) in a matter of seconds and weighs less than 3 lb. Designed for users who frequently test for hazardous toxic substances, the X-pid product line integrates gas detection capabilities via photoionization detector (PID) and gas chromatography (GC) technologies, combining robust analysis with portability. The integrated PID provides measurement in the low parts-per-billion (ppb) concentration range. The PID/GC gas detector also comes with an explosion-proof handheld control unit and mobile app that enable intuitive handling and control. The device's sensor unit compiles measurement values and sends them via Bluetooth to the control unit. Booth 6327 — *Dräger, Inc., Houston*
www.draeger.com

Piping systems for safe conveyance of hazardous liquids

The Double-See vinyl double-containment piping system (photo) is an easy-to-install pressure-rated system with a primary (inner) and secondary (outer) pipe designed for safely transporting hazardous liquids. With the Double-See system, both primary and secondary pipes are cut to the same length and can be joined simultaneously. This saves significant time and prevents potential mistakes caused by staggered pipe-cut measurement errors, according to the manufacturer. Other important features include a unique-to-the-market 3-D thermal-expansion compensation centralizer, and a valve-in-valve design that provides full pressure rating in the containment piping. Booth 1814 — *GF Piping Systems, Irvine, Calif.*
www.gfps.com

These tank assemblies simplify draining

This company's patented Full Drain Outlet (FDO) assemblies for tanks of 2,500 gal and larger (photo) allow tanks to drain without the need for mechanically installed nozzles. The full drain assembly should be utilized where heavy solids or salts can accumulate in the bottom of the tank, thus creating difficult maintenance work. This assembly virtually eliminates the need for confined-space entry, says the manufacturer. Furthermore, the company also offers double-wall tanks for primary and secondary containment of hazardous and corrosive chemicals in capacities from 20 to 8,850 gal. Booth 4457 — *Assmann Corp. of America, Garrett, Ind.*
www.assmann-usa.com

Improve blower performance with this management platform

The Sigma Air Manager (SAM) 4.0 is an adaptive controller platform for improving air generation and treatment. The 3DAdvanced Control functionality analyzes all operating data on an ongoing basis, simulates alternative actions and calculates the optimal combination of compressors, blowers or vacuum units to meet demand. SAM 4.0 not only reduces switching losses, but also takes into account various compressed-air system parameters and uses the gathered information to calculate the optimum performance values. SAM also continuously fine-tunes the system in order to achieve energy efficiency (energy management in accordance with ISO 50001). Secure remote monitoring is offered so that users can view system performance from any PC. As facilities grow, SAM systems can be easily expanded with a simple software update, meaning that there is no need for investment in new hardware. Booth 3625 — *Kaeser Compressors, Inc., Fredericksburg, Va.*

us.kaeser.com

This piping system can handle aggressive chlorinated media

Made from a specially formulated polyethylene (PE) resin, the Chem Proline Advanced PE piping system (photo) is designed to handle very aggressive chemicals, and is NSF 61-G certified. A single-wall piping system well suited for use in water treatment applications, Chem Proline includes pipe, fittings, valves and accessories. Chem Proline is UV-resistant, can be installed above or below ground, and is thermally fused using butt, socket or electrofusion joining methods, which eliminates leak paths at the joints. Chem Proline is said to be the only polyolefin piping system able to handle certain chlorinated or corrosive media, such as sodium hypochlorite, sodium hydroxide, caustic soda and low-concentration acids. Chem Proline's pH capability ranges from 1 to 14, with pressures up to 150 psi and temperatures up to 140ºF. Booth 8104 — *Asahi/America, Lawrence, Mass.*

www.asahi-america.com

Mary Page Bailey

Kaeser Compressors

Asahi/America

Water Management

special advertising section

CHEMICAL ENGINEERING
ESSENTIALS FOR THE CPI PROFESSIONAL
Access Intelligence

Inside:

Profinet communication is gaining ground

AUMA Profinet actuators enhance connectivity at Danish WWTP

(lf) Jens Ulrik Jensen, AUMA sales, and (rt) Søren Præstiin, plant manager with an AUMA Profinet actuator at Måløv WWTP.

Industrial Ethernet communication standards are gaining ground in field device integration, thanks to their outstanding flexibility, reliability and speed. **AUMA**'s electric valve actuators currently support three Industrial Ethernet standards: Profinet, Ethernet/IP and Modbus TCP/IP.

AUMA recently supplied electric actuators with Profinet communications for a modernisation project at a wastewater treatment plant (WWTP) in Måløv, close to Copenhagen, Denmark. Novafos (Birkerød, Denmark) is the plant owner.

"We decided to invest in Profinet communications because Profinet is an open Industrial Ethernet standard with standardised structures", says plant manager Søren Præstiin. A key reason for choosing AUMA actuators was the fact that they are available with direct Profinet connections and so do not require gateways. "We only considered devices with integral Profinet interfaces. AUMA contrasts favourably with other manufacturers", Mr. Præstiin explains.

Profinet combines the robustness of traditional fieldbus networks with the speed and flexibility of Ethernet. It offers full duplex transmission at 100 Mbit/s, comprehensive network diagnostics, automatic configuration and alarm functions.

AUMA's electric actuators with integral Profinet interface meet the requirements of Profinet specification 2.3. An integrated web server handles connection tests, status requests and fault diagnostics. System integration is facilitated thanks to a standardised device description (GSDML) and a Field Device Integration (FDI) package.

www.auma.com

EKATO - Economic Mixing Solutions for Water and Wastewater Treatment

Special impeller for operation in sludge containing long fibers

EKATO EM 2000 / EKATO AQUAJET B impeller

EKATO's offer:

- Detailed process development for water, waste water and biological sludge applications
- Expertise knowledge with successful running plants
- Corrosion resistant coatings to meet your compatibility needs

Advantages:

- To minimize the motor power and the cost of operation
- Safe and reliable mechanical mixing agitator design

Treatment of Drinking Water:

- Continuous operating cleaning processes with high flow rates

The mixing tasks are:

- To achieve a sufficient homogeneity of the reactants at a given middle resistance time
- To support the precipitation-coagulation
- To avoid any damage of the formed flakes in the flocculation step

Treatment of Waste Water Sludge in Fermenters (Digesters):

- In large reactor vessels, (>1000 m^3) viscous sludge must be blended with about 2-8% organic solid content
- Avoid settlement particles at the bottom of the vessel
- Reduction and incorporation of dry solid layers on top of the liquid. The layer arises due to the drying effect caused by the methane gas flow out of the liquid surface
- Preventing entanglement of long fibres that wrap around the impeller blades and shaft by using the **EKATO-Aquajet B** with its special geometry
- The **EKATO-EM 2000** agitator series has several mechanical seal types to handle the explosive conditions

www.ekato.com

The new shape of liquid-solids filtration

FTC provides 176% more effective surface area and fewer filter changeouts with new Invicta technology

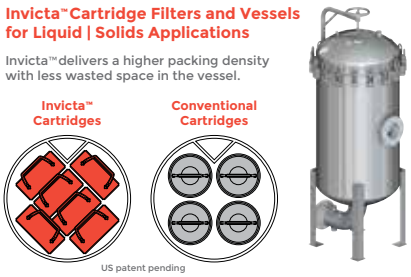
The Invicta cartridge filter and vessel system from **FTC** represents reliable, high efficiency liquid-solids filtration with immediate cost savings for plant operations. Invicta's coreless, trapezoidal filter design delivers up to 2.76 times the effective surface area of cylindrical filters within a given vessel footprint. The Invicta vessel design allows for more filter elements and less unused "dead" space within each vessel. Together, the system delivers absolute-rated filtration, fewer filter changeouts, and the lowest cost of ownership available today.

Conventional, cylindrical filter designs waste precious space in filter vessels, especially when multiple filters are placed in a housing. In contrast, Invicta's innovative design allows for significantly improved element packing density and a longer online life. Longer online life means there are fewer filters to stock, fewer filters to change, fewer filters to dispose of, lower direct and indirect filtration costs, and reduced operator exposure to hazardous process streams.

The Invicta filter and vessel system offers:

- Lowest cost of ownership on the market
- Unmatched effective filter media surface area
- High vessel solids loading capacity
- Absolute rated 99.98% efficiency
- Lower pressure-drop across the vessel
- Improved process reliability
- Fast and easy installation
- Compact storage and disposal
- Rapid vessel upgrades or new Invicta vessels

Invicta cartridges are offered with a broad range of end cap and media options to satisfy most chemical and thermal compatibility needs. Invicta vessels are available in either horizontal or vertical configurations to accommodate space restrictions and customer preference. Common applications for Invicta include water and wastewater, process fluids, hydrocarbons, brines, solvents, amines, glycols, fuels, chemicals, acids, and bases.



FTC's Invicta offers maximum filtration performance and online life while minimizing OPEX and CAPEX.

Contact FTC today to find out more about Invicta and what it can do for your process stream. **www.ftc-houston.com**

Flottweg Wins German Innovation Award in Gold

On May 28, 2019, the winners of the German Innovation Award were honored for the second time at a festive gala held at the Technology Museum in Berlin. More than 350 invited guests from business, politics, and the media accepted the exclusive invitation. The Innovation Prize is awarded by the German Design Council, which was founded in 1953 as an initiative of the German Bundestag. One of the evening's winners was **Flottweg**.

The Vilsbiburg-based company made waves with its Xelletor Industrial Centrifuge and was awarded the German Innovation Award in "Gold" in the category "Excellence in Business to Business – Machines & Engineering".

In their search for maximum separation efficiency, Flottweg engineers and technicians have repeatedly radically questioned the company's existing centrifuge concept. Inspired by the lightweight construction of high-performance sports cars and motorcycles, they came up with the idea of a novel centrifuge design. The heart of the new design, the rotor and decanter scroll, were redesigned from the ground up. The new Xelletor system is thus an entirely new stage of evolution for centrifugal sludge dewatering in sewage treatment plants. The result is a scroll with absolutely no scroll body.

"The dewatering of sewage sludge is standard in the operation of sewage treatment plants. Since the sludge usually has to be transported away, the operators want to separate as much water as possible from the sludge in order to save weight and thus reduce costs. Sewage sludge disposal alone accounts for up to 80 percent of operating costs. With the innovative Flottweg Xelletor System, a specially designed high-performance centrifuge, additional sludge savings of up to 10 percent can be achieved and energy consumption reduced by up to 34 percent. This kind of increased performance in the mechanical separation process with significantly lower consumption has redefined the standards in the field of industrial centrifuges," stated the German Innovation Award jury.

With the German Innovation Award, the German Design Council honors forward-looking innovations that have a lasting effect and offer added value for the user. A total of 695 submissions were received this year, some from industry giants such as Samsung, Bosch, Deutsche Telekom, and the Swiss ABB group, as well as from hidden champions and start-ups.

The German Design Council – the awards body

The German Innovation Award is initiated and implemented by the German Design Council, which was established by the German Bundestag in 1953 and is a foundation of the Federation of German Industries (BDI). For 66 years now, the foundation has pursued the goal of promoting the competitiveness of German companies.

www.flottweg.com

Flowrox Reinforces Its Filtration Portfolio

Flowrox, formerly known as Larox Flowsys, has more than 40 years of experience in solid/liquid separation, flow control, elastomer technology and technical textiles. After acquiring American Spare Parts Depot and NovaTek, Swedish filtration technology company, Flowrox strengthened its filtration portfolio.

Flowrox Filtration Solutions

The team of experienced Flowrox professionals provides you with the whole package of services starting with a detailed analysis of the process, filtration testing, equipment selection and sizing according to the test results and practical experience. Flowrox offers full support at delivery, installation, start-up, operation and maintenance. Modernizations, refurbishments, spare parts and maintenance support are also available.

Flowrox Filter Press (FP) was engineered together with plant operators and is well appreciated especially among leading global metal production companies. Flowrox FP presents fully automatic operation, high quality, superb performance and high availability. Common applications for Flowrox Filter Press are zinc refinery processes, silver, gypsum and chlorine removal, polishing, wastewater streams, flue-gas desulfurization and energy metals.

Flowrox Ceramic Disc (CD) Filter is highly efficient and has the lowest energy consumption. Besides that, it requires low investment and delivers clear filtrate with a dry cake. Compared to conventional vacuum filters, it consumes approximately 90 % less energy. Flowrox CD filter operates continuously with high capacity and is a cost-efficient solution for many concentrator and tailings processes. Applications for Flowrox CD filter are divided into concentrates and tailings. The concentrate applications most suitable for the Flowrox CD filter are iron, copper, zinc, gold and phosphates. Typical tailings applications are iron, copper, molybdenum, phosphorus and quartz sand.

Improve Process Performance with Smart Solutions™

Flowrox Smart Solutions are a new way to combine processes and Industrial Internet of Things (IIoT). Specifically for filtration, Flowrox has developed a Flowrox Smart Filtration Digital Service, a turnkey solution that can be installed on any filter. It enables remote, real-time insight into the filtration process and helps to troubleshoot and significantly optimize production. Smart Filtration utilizes existing control system and sensors and connects the filters to the Flowrox Malibu online portal. DCS (Distributed Control System) integration is not necessary, but it can be arranged upon request. Malibu also automatically generates user-defined reports which are easy to read. Data analysis provided by Smart Filtration can be used for comparing filter's productivity, quality changes, energy consumption, and production output, to determine the reasons for its waiting time, alarms and more. **www.flowrox.com**

Flowrox Filter Press (FP) presents fully automatic operation, high quality, superb performance and high availability.

Proven Reliable and Energy-Efficient Solutions for Wastewater Treatment

It's no secret that factory-built blower and compressor packages provide distinct benefits and savings. That's why wastewater treatment plants across the country rely on industry leader Kaeser Compressors, Inc. for their blower and compressed air needs.

For design packages that include a complete scope of supply with motors, drives, valves, enclosures, and instrumentation, plant managers and operators can count on Kaeser for simplified installation, reduced maintenance costs, superior energy efficiency and years of trouble-free performance.

Kaeser's manufactures rotary lobe, rotary screw, and high speed turbo blower packages that are perfectly suited for wastewater service. In addition to excellent reliability, they offer side-by-side installation with a compact design that's built for a lifetime. Sound dampening and anti-vibration features bring noise levels down so low you won't believe they're running.

With over 100 years as an industry leader in the manufacture of industrial compressed air, blower, and vacuum equipment, Kaeser is committed to finding new and innovative ways to make their blowers and compressors more efficient, reliable, and keep with the quality customers have come to expect from the Kaeser name. From cabinet design to placement of fans and vents, to even the feet of the machines, Kaeser is always looking for ways to make the use and generation of compressed air more cost-effective.

Kaeser's custom engineered compressed air systems are yet one more way show the innovative spirit and deliver lasting value to their customers. Kaeser is not intimidated by demanding applications. Their commitment to designing the best engineered solutions results in compressed air systems that remain reliable even in the toughest of applications in the harshest of environments.

The turnkey, all-weather Custom Engineered Solutions are compressed air packages that integrate their high quality compressed air systems with rugged, weather-proof containers or skids. Remote operations are supported by the revolutionary Sigma Air Manager 4.0, which controls air production and offers a variety of industrial communications interfaces for seamless integration into the IIoT.

At the upcoming WEFTEC show in Chicago, Kaeser will be running an energy-efficient skid-mounted system that includes their complete rotary screw blower packages with integrated variable frequency drive and advanced adaptive master controller. Also on display will be Kaeser's new high speed turbo blower. Come by booth #3625 to see how Kaeser can reduce your installation, maintenance, and energy costs.

www.us.kaeser.com/chemeng

Static mixers with low pressure drop

Ross LPD Low Pressure Drop Static Mixers are ideal for effective fluid mixing in water and wastewater treatment processes

The **Ross** Low Pressure Drop (LPD) Static Mixer enables more efficient dosing of flocculants, disinfectants, neutralizing agents and pH conditioners into a water stream. This simple-to-install heavy-duty device completely mixes treatment chemicals within a short length of pipe. When used in conjunction with automated instrumentation, the LPD delivers predictable quality control based on a virtually maintenance-free operation.

Four or six mixing elements are usually more than sufficient for effective mixing under turbulent flow conditions, Ross says. Diameters range from 1 in. through 48 in.

The LPD Static Mixer consists of a series of baffles or "elements" discriminately positioned in series. Each element comprises a pair of semi-elliptical plates set 90 degrees to each other. The next element is rotated 90 degrees about the central axis with respect to the previous baffle set, and so on. For even lower pressure drop, an LLPD model is also available, in which the plates of each element are oriented at 120 degrees relative to each other.

As the fluid moves through each LPD or LLPD element, flow is continuously split into layers and rotated in alternating clockwise and counterclockwise directions. This method of subdividing the stream and generating striations leads to highly efficient and repeatable mixing with minimal pressure loss. During turbulent flow, the baffles enhance the random motion of molecules and the formation of eddies. In most water and wastewater processes, four or six elements are more than sufficient to completely disperse treatment chemicals and create a very uniform solution or suspension.

Small LPD/LLPD mixers of 1 in. through 2.5 in. in diameter are welded to a central rod, while larger elements are welded to four outside support rods for maximum rigidity and stability. Available in a wide range of sizes up to 48 in. in diameter, these mixers can be supplied as pipe inserts or as complete modules with housing and injection ports.

In addition to Static Mixers, Ross also manufactures High Shear Mixers and Multi-Shaft Mixers used in the production of water treatment chemicals. The company offers no-charge mixer testing services and an extensive trial/rental program.

www.mixers.com

Ultra-High Efficiency Gas Absorption and Particulate Collection in a Space Saving Design

Now Achievable with Proprietary Bionomic Scrubber Technology

Overview

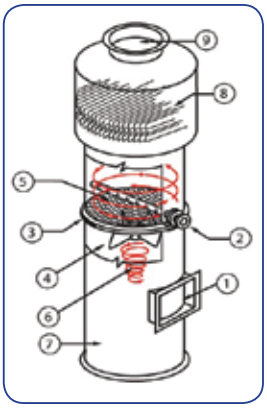
The patented **RotaBed™** Fluidized Bed Scrubber represents a major breakthrough in ultra-high efficiency gas absorption and particulate collection in a space saving non-fouling design. RotaBed is the ideal technology for applications involving particulate laden gas streams or when handling high solids content or scale forming scrubbing liquids.

The key to the scrubber's superior performance is a unique swirl induced Coriolis grid that achieves much greater fluidized bed stability, resulting in more efficient gas mixing and transfer efficiency than less advanced designs. This unique approach to gas-liquid fluidization is accomplished without the need for marbles or plastic spheres that are prone to fouling or replacement due to wear. RotaBed's "packless", highly plug resistant grid cross section is up to 99% open in the fluid contact scrubbing zone and allows the scrubber to deliver exceptionally high gas throughput capacity - over three times greater than comparable size packed towers or tray scrubbers for higher scrubbing efficiency in a smaller diameter vessel.

Designed to handle gas capacities from 500 thru 25,000 cfm, RotaBed is available in mild steel, 304, 316, and AL6XN Stainless Steels, High Nickel Alloys, Titanium FRP, FRP-Dual Laminate, and Polypropylene. Pressure drop range is 1..75" thru 15" w.c. with particulate removal efficiencies of 3 microns and above from 97 to over 99.9%, and water soluble gases up to 99.99%

How It Works

During operation, gas with contaminants enters the RotaBed gas inlet(1) and flows upward. Scrubbing liquid is introduced through fully open non-clog pipe distributors(2) onto the surface of the patented RotaBed Coriolis induced fluidizing grid(3). Single or multiple grid stages are incorporated depending on the number of transfer units required to meet the needed pollutant removal efficiency. The high velocity gas travels in an angular upward path and fluidizes the liquid on the large open area grid surface. Unlike low efficiency static plug flow fluidized beds, the RotaBed shaped grid design utilizes swirl inducing vanes(4) to dramatically increase mass transfer and particulate collection via creation of a rotating Coriolis motion fluidized bed(5). Scrubbing liquid with captured pollutants then vortex drains(6) into the slump(7). The RotaBed cleaned gas passes through a two stage droplet removal stage(8) and exits through the gas outlet(9).



How RotaBed™ Works

www.bionomicind.com

80 GHz radar for reliable pump control

Chemical plants have a lot of processes to manage, and pump control at their water treatment facility is often overlooked – until something goes wrong. Using 80 GHz radar technology for level measurement and pump control can save facilities hundreds of thousands – even millions – of dollars in maintenance and repair costs. The level and pressure experts at **VEGA** were the first to bring 80 GHz radar technology to market, and since then, they've helped countless facilities around the world reduce costs and improve their processes.

The VEGAPULS 64 is an 80 GHz radar sensor, specifically designed for liquid level measurement. The higher frequency gives the radar sensor a narrow 3° beam, providing more focus and allowing users to make an accurate and reliable measurement in the tightest of spaces. The narrow radar beam can shoot down to the surface of the fluid below without hitting any pipes, struts, or other obstructions that may be crisscrossing near the opening or farther down.

VEGAPULS 64' narrow radar beam provides more focus, thus allowing users to make an accurate and most reliable measurement.

The VEGAPULS 64 also uses a higher 120 dB dynamic range, which gives the radar a higher sensitivity. This is especially important since water treatment processes collect everything from rainwater and debris to oil, foam, and grease. Less sensitive radars and other measurement instrumentation have struggled with such a mixture of fluids in the past, leading to faulty measurements and costly repairs.

Upgrading the level measurement for pump control in the water treatment process at any chemical plant can save time and money, freeing up valuable resources for improving processes that affect the bottom line. The VEGAPULS 64 can provide an accurate and reliable non-contact measurement that keeps the pump running when it should be.

www.vega.com

Smart actuator optimizes control valve performance

The new Smart Electric Valve Actuator (SEVA) from Badger Meter stands up to extreme conditions while providing exceptional position accuracy

Since 1905, **Badger Meter** has been recognized as a leader in the development and manufacture of flow management solutions. The company has introduced the latest generation of its Smart Electric Valve Actuator (SEVA) solution, which now offers Modbus RTU, Modbus TCP/IP and SoloCUE® connectivity.

SoloCUE connectivity

SoloCUE is a software solution that provides easy access to the setup of both the feature-rich SEVA and its protocols. This custom-built, bulletproof platform allows end-users to visualize SEVA's performance and setup characteristics.

Product design

SEVA employs cutting-edge technology and delivers exceptional accuracy and repeatability. Designed for extreme conditions, the actuator has military-grade components.

SEVA has 100-lb. and 200-lb. thrust models. There are several options available for communication protocols, including Modbus RTU, Modbus TCP/IP and the Industrial Ethernet Protocol (EtherNet/IP). It is is certified by FM, EX, CSA and CE. The actuator allows for both linear and Device Level Ring (DLR) ring network topologies.

Position accuracy

SEVA provides an exceptional level of position accuracy (±1% of full scale) with five available positions when there is a loss of power. The device also features four positions when there is a loss of signal. Both the full closed and full open positions are defined during setup.

In addition, SEVA has an internally powered (active) feedback signal, which actively communicates stroke position to the control system. Its feedback sensors are crucial in more precise applications. SEVA even provides a manual override capability to help the operator in loss-of-power situations.

Other features

The SEVA assembly has the option to include two user-adjustable limit switch outputs. An external signal is provided once the set points of the limit switches are met. Furthermore, the electric actuator can split the incoming 4–20 mA signal and use either the lower or higher range of the signal for full stroke operation. A hyper terminal server makes it possible to change the type of split range.

SEVA was specifically designed to minimize the number of models needed to work with different electrical demands. Its Universal AC Input with voltage protection will work with 115 V AC, 230 V AC and 24 V DC power supplies. This feature ensures confidence that the actuator will provide a single source for different process needs. SEVA can receive analog input signals from 4–20 mA, 0–5 V DC or 0–10 V DC.

To learn more, visit us at booth #1920 during WEFTEC 2019 and booth #308 during the Chem Show 2019.

www.badgermeter.com/chemicalSEVA

Modern Instrumentation Simplifies Maintenance

A typical maintenance strategy in a chemical plant involves performing planned routine maintenance and reacting only when equipment fails. To help improve upon this situation, instrumentation is getting "smarter" with functions such as self-diagnostics and condition monitoring (Figure 1).

NAMUR NE 107 is a standard that every instrument manufacturer follows. It provides diagnostic codes with clear messages and remedies, including maintenance required, function check, out of specification, failure and others.

Modern instruments can easily provide this data because almost all instruments from major vendors employ self-diagnostics. Self-diagnostics means an instrument is capable of detecting when it has a problem by monitoring internal parameters related to its mechanical, electromechanical and electronic components.

Depending on the industry, instruments must be calibrated periodically. For example, the chemical industry has requirements for proof testing per IEC 61508 and IEC 61511.

When calibration is scheduled every six months or so, processes may have to be shut down while the instrument is taken to a lab and calibrated. Many instruments are found to be perfectly calibrated, proving much of the process unnecessary and costly. Self-verification avoids this unproductive effort.

A self-verification is initiated on command from the automation system or at the instrument. During self-verification, diagnostic routines perform checks and generate a report which verifies the device is working properly.

Endress+Hauser's Heartbeat Technology complies with requirements for verification according to DIN EN ISO 9001:2008, Section 7.6a, "Control of monitoring and measuring equipment."

Processing all the data from a plant's instruments can be challenging because a typical chemical plant has thousands of instruments. Using the control system to read diagnostic information from all of these instruments, analyze it and issue instructions to the maintenance department can be a daunting challenge.

Modern instrumentation, such as this Endress+Hauser Coriolis flow meter, have built-in diagnostics and condition monitoring.

Therefore, instrument manufacturers have developed two main types of software packages to perform these functions. Instrument management programs, which analyze real-time information from instrumentation; and asset management software, which keeps track of every instrument in the plant and stores vital data, such as manuals and parts lists.

Modern instrumentation and supporting software could replace conventional maintenance strategies, saving time and money. Proper use of these software packages will also greatly improve reliability and availability of the facility by diagnosing and predicting device failures.

www.us.endress.com

Waste Drainage Problems Draining You? Consider Upgrading to Kynar® PVDF Systems

Kynar® PVDF piping can offer upgraded performance over commodity plastics

Plastic drainage systems for laboratory and chemical waste containment are commonly installed to safely convey a variety of fluids. From diluted chemicals to aggressive by-products and heat caused from mixing chemicals, it is important that containment systems can withstand any challenge. For highly aggressive fluids, or high temperature challenges, **Kynar®** fluoropolymer piping offers nearly universal chemical resistance for low-pressure service and is rated at 150C per UL® RTI testing.

Kynar® PVDF, like other polymers, is lightweight and easy to join using mechanical fittings or electrofusion. Complete waste drain systems are available up to 10" diameter (larger diameters can be fabricated) and are UL® listed and labeled meeting the stringent requirements of ASTM E84 (25/50) without modifications to the test standard, ULC S102.2, and NFPA 90A Standard for the Installation of Air-Conditioning and Ventilating Systems, for use in plenums and concealed spaces.

Kynar® 740-02 piping installed in plenum to transport acidic waste.

Combination of Kynar® 1000HD and Kynar® 740-02 piping in underground concealed space.

The availability of chemical waste drain systems is complimented in industrial applications by the availability of Kynar® PVDF lined steel, FRP dual laminate Kynar® PVDF lined pipe, Kynar® PVDF Schedule 80 & SDR solid pressure pipe systems, and Kynar® PVDF biotech flexible tubing systems mechanically connected to injection molded Kynar® PVDF fittings. Based on lifetime performance, these systems, when used to handle hot strong acids, bleach, bromine, and changing chemical mixtures, are cost effective vs. exotic metals, fluoropolymers, and other engineering polymers.

www.kynar.com

Water Filter Applications for the Petrochemical Industry

There are many areas within petrochemical processing which use water that requires filtering.

By using a **Tekleen** self-cleaning automatic filter, this water can be cleaned of debris and solids, provide cooling, pre-filter water for further cleaning, and maintain the operational reliability of piping, spray heads and any devices that water flows through.

It can be used as a pre-filter down to 2 microns, protecting R/O and microfiltration systems used for potable water quality production. The filtered water can then be re-used and the debris properly disposed of. The filters operate on line pressure alone.

Types of Water Filter Applications for the Petrochemical Industry

1. Reverse Osmosis

This process uses reverse osmosis semi-permeable membranes to flush out impurities.

High pressure water is passed through the membrane, leaving behind contaminants and particles.

2. Cooling Water Tower

The water is cooled throughout the cycle by evaporation, which results in debris accumulation. With a Tekleen automatic filter, the debris is filtered out and contained for disposal, the filter cleans itself, and the cooling water continues to flow.

One such installation for providing cooling tower water uses a Tekleen 6" filter, with a flow rate of 600 GPM, at 50 PSI. The filter used is an ABW6-LP with a 100 micron high performance screen.

3. Underwater Pelletizing

Underwater pelletizing is a method of cutting extruded plastic into beads. This water can be recycled.

4. Potable Water

Petrochemical companies often provide potable water in housing and break room for employees. Tekleen filters can purify this water down to 2 microns to prefilter water going through an R/O or microfiltration process for safe drinking.

5.Polymer Filtration - used to settle mud

With the mud adequately settled and turbidity minimized, the Tekleen unit can filter the re-usable water, which can be sent to storage. The polymer beads are left behind to continue the settling process.

6.Well Water Seal Protection

Seals can be protected from excessive wear by using water to cool down the seal and the shaft, to lubricate the seal, and to flush away solids. One Tekleen installation uses a 2" filter, setup to provide 100 GPM. It uses a MTF2-XL 25 micron screen.

Several of the largest U.S. petrochemical plants use Tekleen filters for their various water requirements.

With proper filtration, source water for processing can successfully be derived from wells, ponds, rivers, rainwater, seawater and re-used water.

Tekleen self-cleaning water filters provide the ultimate solution where dirty water is a problem.

www.tekleen.com

Ultrapen PTBT1 Smartphone/ Tablet Compatible Tester

The Myron L® Company's new ULTRAPEN™ PTBTx™, wireless Pocket Testers are designed to be paired with any Apple® iOS 8+ device via the ULTRAPEN's Bluetooth® BLE transceiver. A free App takes advantage of Apple's iOS GUI to provide easy-to-read displays and a simple-to-use interface. The Bluetooth link means that there are no bothersome wires getting in the way when moving quickly between samples and that paired mobile devices can be held safely away from liquids.

Advanced features include: Automatic temperature compensation; stable microprocessor-based circuitry; user-intuitive design and a rugged, waterproof housing.

Available models:

- ▶ PTBT1 - Conductivity, Total Dissolved Solids (TDS), Salinity, and Temperature measurement with three, selectable solution modes that model commonly encountered water types.
- ▶ PTBT2 – pH and Temperature measurement with 1, 2, and 3 point calibration options.
- ▶ PTBT3 - ORP & Temperature measurement.

Using your ULTRAPEN iOS App:

- Each ULTRAPEN PTBTx can be given a unique name stored in the ULTRAPEN's memory so it is easily identifiable no matter what mobile device is used.
- Measurement locations can be programmed as:
  - o GPS locations that are automatically selected when the user is close to a specific measurement local, or;
  - o Non-GPS locations ideal for applications where the sample sites are too close together for the GPS to discriminate.
- Measurements can be saved to the mobile device's memory including measurement data, ULTRAPEN settings, sample temperature, ULTRAPEN name and measurement location.
- Records can be exported via the mobile device's email function as either .csv, .xls, .xlsx formatted files or using Myron L Company's .mlc, proprietary, encrypted format.
- Stored measurements can be sorted or filtered and then emailed or deleted without affecting other records stored in memory.

Coming Soon:

- ▶ PTBT4 - Free Chlorine Equivalent (FCE™) & Temperature measurement.
- ▶ Android™ compatible App.

www.myronl.com

Compact. Flexible. Cost effective.

GEMÜ 3030 mFlow

These compact and flexible components are available at a low cost and in high demand in the plant engineering sector. Thanks to its varied application acceptance, the GEMÜ 3030 mFlow is a more cost-effective option than conventional flowmeters.

Magnetic induction as a measurement principle

With this 3030 mFlow measurement principle, a moving conductor induces a voltage in a magnetic field which is proportional to the speed of the flowing medium. The flowing medium, which must be electrically conductive, (≥ 20 µS/cm) is the moving conductor. This makes it possible to measure the flow velocity of liquids precisely. The flow rate is then calculated using the pipe cross section previously entered by the user. Flow velocities are measured between 0.1 - 10 m/s. The measurement result is largely independent of process pressure, temperature and viscosity.

The GEMÜ 3030 mFlow operates reliably with conducting media in a temperature range of 0 - 135 °C with a supply voltage of 24 VDC and an automatic adaptation of the measuring range (0 - 4 m/s or 0 - 10 m/s). For optimal performance, the ambient temperature should not exceed 60 °C or fall below 0 °C.

The magnetically inductive flowmeter can be used up to a maximum operating pressure of 10 bar.

Application in many sectors

The GEMÜ 3030 mFlow is suitable for a wide range of uses in the most varied of industrial sectors. In most cases, this entails the measurement of all types of liquid media.

Thanks to its contactless measurement principle, the flowmeter can also measure media with particles; such as to measure fruit juices. Besides the beverage industry, the GEMÜ 3030 mFlow can also be used for water treatment.

A huge variety of advantages

- Bi-directional measurement permits installation independent of the flow direction. However, we recommend installation in the flow direction indicated on the devices. Due to the measurement principle, there are no moving parts in the medium.
- The GEMÜ 3030 mFlow contains two totalizers, enabling the flow to be determined over a specific time period. Depending on requirements, these totalizers can be reset, enabling hourly, daily, monthly or annual values to be determined.
- The GEMÜ 3030 mFlow can be fitted with a temperature sensor which makes it possible simultaneously to detect the flow rate value and the medium temperature.

Visit GEMÜ at WEFTEC Booth 5161 **www.gemu-group.com**

Multiple Temperature Points – One Sensor

In any manufacturing operation, there are a variety of process variables that are monitored, measured and/or controlled. One of the most widely measured variables is temperature. The temperature of a material (be it gas, liquid or a solid) is seldom constant throughout the process. In some applications, small variations of a material temperature within the process may not be an issue, but in others, it is critical to monitor and/or control at a number of points. Measuring temperature of a process at multiple points can be accomplished by mounting an individual sensor at each location or by installing a single multi-point temperature sensor assembly. Both will provide the necessary information, however the multi-point sensor only requires one installation at one location with one control connection while measuring the material at numerous points along the process. Multi-point temperature sensors provide an economical and efficient way to handle several points of measure in a process.

In its simplest form a multi-point temperature sensor consists of a number of RTDs (Pt100s) or thermocouples encased at various points inside a sleeve, sheath, jacket or tube with a single access point at a junction enclosure. Multi-point sensors can be various lengths, sizes in diameter, made of a variety of materials, incorporate temperature transmitters, and constructed to measure a wide range of temperatures.

Multi-point temperature sensors are utilized in many industries, including but not limited to:

- chemical
- oil and gas
- petrochemical
- food and beverage
- dairy
- pharmaceutical
- power generation
- HVAC
- heat treating
- water and wastewater

These sensors are often used to measure multiple temperature points in storage tanks, piping systems, ovens/kilns/furnaces, air flow ducts, grain bins, heat exchangers, rail car and truck tanks, distillation columns, chemical vessels and others.

Depending on the application, multi-point temperature sensors provide detailed temperature profiles for optimized process control. They are often used to map temperatures over a large area, identify temperature gradients, or to detect hot spots within the process.

Pyromation manufactures a variety of standard and custom-designed multi-point temperature sensor assemblies that are used in applications in many industries around the world.

www.pyromation.com

A Flexible Solution to Better Visibility

Emerson's technologies make it easier for refining and petrochemical manufacturers to include compressors in operational performance improvements

Compressors operate at the heart of many refining and petrochemical production processes. Compressor performance impacts efficiency, safety, production, and energy usage. Today, many compressors operate as a standalone "black box" on a programmable logic controller (PLC). Such a configuration can limit potential for performance improvements driven by data integration and analytics—key digital transformation enablers.

Forward-looking organizations are continually evolving compressor control. These organizations are designing greenfield and modernization projects that integrate compressor control into the balance of the plant for total plant control and greater insight into performance.

Modern hybrid automation controllers such as the DeltaV™ PK Controller support digital transformation initiatives with compressor control capabilities. When well integrated, these systems can provide improved anti-surge control and optimization, better compressor and auxiliary device control, mechanical state and valve instrumentation diagnostics, maintenance procedures optimization and more.

Advanced technologies in the DeltaV PK Controller make it easy to gain visibility of compressor health.

- **Powerful Standalone. Easily Integrated.** The DeltaV PK Controller can operate as a standalone controller for compressors to fit the plant's current configuration and later be merged into a DeltaV distributed control system (DCS). Native integration into the DeltaV DCS and flexibility for OEM modular construction significantly reduce the engineering and mapping necessary with many PLCs. This provides capital project efficiency, while enabling operational performance improvements.
- **Future-ready technology.** Ethernet connectivity and a built-in OPC UA server allow the DeltaV PK Controller to provide advanced integration out of the box. Easily and securely connect to Industrial Internet of Things (IIoT) devices, cloud-based analytics, and third-party software for total plant control and insight into compressor performance.

- **Eliminate islands of automation.** Integration into the balance of the plant breaks down data silos, providing faster access to critical compressor health data and enabling operators to have insight into the total productivity and reliability of their plant.

An asset doesn't have to be miles away to be stranded. A compressor that cannot be integrated into the plant environment limits control and reduces productivity. Flexible control technologies like the DeltaV PK Controller can help you solve today's problems fast, while simultaneously preparing operations for digital transformation.

www.emerson.com/deltavpkcontroller

Not at the forefront of Industry 4.0?

Enhanced automation solutions with IIoT technology like the proven Metris addIQ control systems from ANDRITZ have been showing their worth in all kind of solid/liquid separation applications with great success. Customers who are already using these systems profit from the opportunities that come with digitalization and IIoT, such as risk elimination, efficiency optimization, and profit maximization.

Optimal process performance demands accurate data – anytime, anywhere. Metris addIQ Connect and Metris addIQ Monitoring are customized to give you precisely the information you need, when and where you need it most. Metris addIQ Monitoring displays your most important process parameters, for a single machine or an entire plant, and then uses Metris addIQ Connect to link it to a secure data cloud – providing you with 24/7 access from anywhere in the world. This solution also includes an automatic notifier for the most critical process alerts, enabling remote support when fast action is needed.

For a municipal wastewater treatment plant in southern Germany, this included easy-to-access performance and trend reports, real-time sludge flow and polymer dose monitoring, long-term process data, etc. Everything is tailored to give a transparent overview of the customer's facility, improve process performance, and prevent unplanned shutdowns.

Metris addIQ Optimizing further boosts the plant's performance by identifying ways to increase performance and production, as well as enabling predictive maintenance as a way to significantly decrease downtime.

An intuitive operator design ensures full-scale efficiency in operation and reduces the risk of operation errors with the right HMI (Human Machine Interface) – for an individual machine or an entire plant. The overall usability concept takes the various requirements of the operating staff into account and enables operators with different levels of experience to fulfill their tasks within the same time period.

With perfectly matched state-of-the-art hardware and software, you are prepared for the future with unique and innovative products such as the **ANDRITZ** intelligent filter press uniting most of the Metris addIQ portfolio and IIoT solutions. Combining an intelligent filter plate and Smart Sensors with sophisticated data collection, analysis and optimizing tools, this filter press is able to operate fully automatically while also optimizing and increasing production capacity. An intelligent filter plate measures moisture content which enables online monitoring to stop the process at the right time. Combined with Metris SmartFILTERCLOTH, a tracking system that helps you to monitor the use of your filter cloths, use of these wear parts becomes more transparent, helping to further optimize the process and maximize equipment availability.

The unique ANDRITZ IIoT solutions already have a track record of realizing more than 350 million euros annually in savings for its clients, and this figure keeps on growing. Thanks to the strong network of 2,000 separation specialists in 40 countries, ANDRITZ is always ready to lend a helping hand – anywhere and any time in the world.

www.andritz.com/separation

Economic Indicators

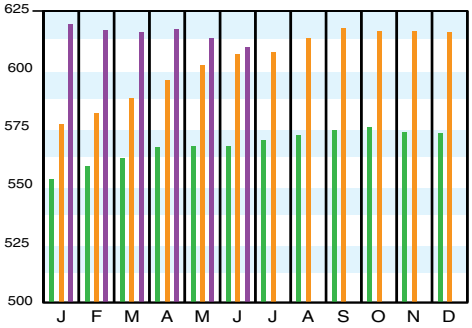
2017 2018 2019

Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	June '19 Prelim.	May '19 Final	June '18 Final
CE Index	609.7	613.5	605.2
Equipment	743.3	748.7	738.1
Heat exchangers & tanks	659.7	665.8	654.0
Process machinery	727.2	730.7	716.9
Pipe, valves & fittings	955.7	965.4	967.7
Process instruments	416.6	419.0	427.9
Pumps & compressors	1068.5	1068.9	1017.9
Electrical equipment	557.7	557.6	536.2
Structural supports & misc.	810.9	818.0	805.3
Construction labor	336.2	335.6	332.3
Buildings	596.0	597.8	600.8
Engineering & supervision	314.3	316.4	307.3

Annual Index:
2011 = 585.7
2012 = 584.6
2013 = 567.3
2014 = 576.1
2015 = 556.8
2016 = 541.7
2017 = 567.5
2018 = 603.1

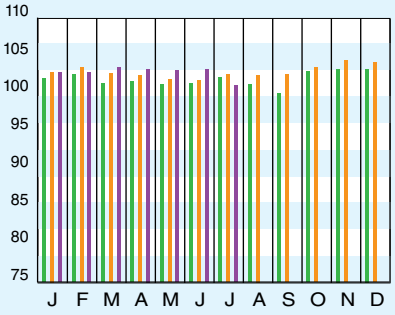


Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

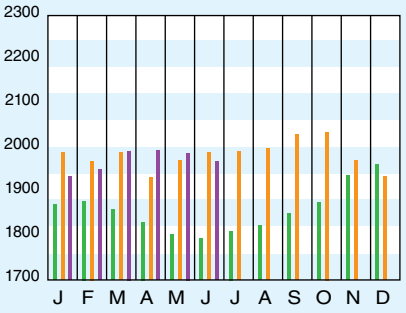
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS		YEAR AGO
CPI output index (2012 = 100)	Jul.'19 = 101.0	Jun.'19 = 101.5	May '19 = 101.6	Jul.'18 = 103.7
CPI value of output, $ billions	Jun.'19 = 1,969.6	May '19 = 1,984.8	Apr. '19 = 1,992.9	Jun.'18 = 1,988.1
CPI operating rate, %	Jul.'19 = 75.3	Jun.'19 = 75.7	May '19 = 75.9	Jul.'18 = 78.1
Producer prices, industrial chemicals (1982 = 100)	Jul.'19 = 256.3	Jun.'19 = 259.3	May '19 = 257.4	Jul.'18 = 274.2
Industrial Production in Manufacturing (2012 =100)*	Jul.'19 = 104.7	Jun.'19 = 105.1	May '19 = 104.5	Jul.'18 = 105.2
Hourly earnings index, chemical & allied products (1992 = 100)	Jul.'19 = 186.0	Jun.'19 = 185.1	May '19 = 184.9	Jul.'18 = 183.7
Productivity index, chemicals & allied products (1992 = 100)	Jul.'19 = 94.6	Jun.'19 = 94.9	May '19 = 94.3	Jul.'18 = 97.7

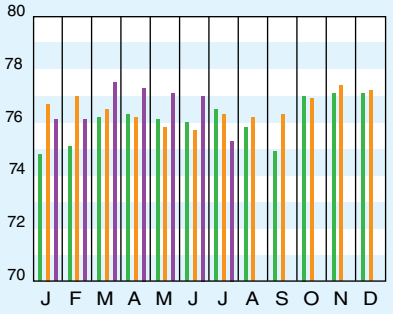
CPI OUTPUT INDEX (2000 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2000 to 2012
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top; the most recent available) for June 2019 decreased from the previous month's value. The decline is the fourth within the last five months. Decreases in the Equipment, Buildings and Engineering & Supervision subindices offset a small increase in the Construction Labor subindex to arrive at the lower value for the overall CEPCI in June. The final overall CEPCI value for May 2019 was revised slightly upward in June. The preliminary June CEPCI value is 0.8% higher than the corresponding value from a year ago. Meanwhile, the CBI numbers for July 2019 (middle) show a decrease in the CPI output index for July, as well as declines in the CPI operating rate and producer prices.